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THE EFFECTS OF A RIBBED WALL ON THE EFFICIENCY OF A WIDE ANGLE SUBSONIC DIFFUSER

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ARO, Inc.

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ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

THE EFFECTS OF A RIBBED WALL ON THE EFFICIENCY OF A WIDE ANGLE SUBSONIC DIFFUSER

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FOREWORD

The work reported herein was done at the request of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65402234, Project 6950, Task 695002.

The results of the research presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center, AFSC, Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1200. The test was conducted from January 20 to May 21, 1965, under ARO Project No. PR3423. The manuscript was submitted for publication on March 3, 1966.

This technical report has been reviewed and is approved.

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ABSTRACT

Tests were conducted to determine the effects of a ribbed wall on the efficiency of a single side expanded, wide angle, subsonic diffuser. Rib geometry, diffuser angle, Reynolds number, and Mach number were varied. Except at low Reynolds numbers, ribs were found to improve the efficiency of the diffuser. They were also more effective than vortex generators except at low Reynolds numbers for all Mach numbers and at high Mach numbers for all Reynolds numbers. The ribs produced maximum improvement at diffuser angles of 20 to 22 deg. The data indicated that the depth-to-width ratio of the grooves between the ribs should be in the range of 2 to 6. The range of Reynolds numbers and Mach numbers over which the ribs were effective appeared to be primarily a function of the groove width.

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SECTION I
INTRODUCTION

Recent Union of Soviet Socialist Republics (U.S.S.R.) research in subsonic diffuser design (Ref. 1) indicates that the efficiency of a wide angle subsonic diffuser can be increased at high Reynolds numbers by cutting transverse ribs in the wall of the diffuser downstream of the diffuser entrance. Reference 1 consists of limited excerpts of reports of the research conducted in the U.S.S.R. on ribbed diffusers. The available excerpts are incomplete, and related U.S.S.R. reports, if any, are unavailable. Some of the highlights of the excerpts are presented here; however, it should be noted that the translations are not clear on many points.

Several tests were conducted in the U.S.S.R. with various types of diffusers. The information given in the excerpts describing the test article and test conditions is tabulated in Table I.

Test 1 showed that transverse ribs increased diffuser efficiency by a factor of 2 above a critical Reynolds number of about 9×10^4. Below $Re = 9 \times 10^4$, efficiency decreased with decreasing Reynolds number to some minimum Reynolds number below which the effect of ribs was negligible.

Test 2 showed that increasing the number of ribs above eight did not further increase the diffuser efficiency.

In Test 3, the ribs again increased the efficiency by a factor of 2; however, the results were not affected by Reynolds number. Also the ribbed diffusers exhibited a more uniform flow field at the diffuser exit. In addition, two other significant observations were made in Test 3: 1) The ribs were not effective unless the position of the first groove was upstream of the flow separation point for the smooth diffuser; 2) The ribs must be flush with the surface of the diffuser; ribs protruding into the flow field increased the intensity of flow separation and decreased the efficiency.

Test 4 indicated that a ribbed diffuser with $\beta = 31$ deg experienced a minimum in efficiency at inlet velocities of 50 to 60 m/sec. This was attributed to the possible emission of acoustic waves from the grooves. The acoustic waves were caused by resonance which occurred when the frequency of vortex decay at the "end" of a rib coincided with the natural frequency of air vibration inside the groove. Maximum increase in efficiency occurred at $\beta \approx 40$ to 45 deg. For these angles, the efficiency

was 2.2 to 2.4 times that of the smooth diffusers. At large opening angles ($\beta \approx 60$ deg) the flow was separated at the diffuser inlet rim and did not interact with the ribs. Inlet rims were made with different curvature radii, and the position of the first groove was varied up to a point at which it was located at the inlet rim. However, in all instances for $\beta \approx 60$ deg, the efficiency was no greater than that of the smooth diffuser. With decreasing β ($\beta < 40$ to 50 deg), the intensity of flow separation in the smooth diffuser decreased, and consequently, the favorable effect of ribs decreased. At $\beta \approx 20$ deg, the ribs had practically no effect on efficiency. Ribs in annular diffusers gave a slightly smaller increase in efficiency than in conical diffusers. A ribbed diffuser with $\beta = 40$ deg gave efficiencies equivalent to a 20-deg smooth diffuser. Based on results of tests 1, 2, and 4 on conical diffusers, it was concluded that within the range of parameters studied, changing the scale of the diffuser and rib section had no effect on the efficiency.

Test 5 was conducted on a flat diffuser with one-sided expansion to study the effects of groove depth (a), groove width (b), and number of ribs. The results of this study are presented in Fig. 1. The author concluded that to obtain a favorable effect of ribs, the grooves should be sufficiently deep so that stable vortices are formed. This occurred for a depth-to-width ratio, a/b, of 2.0 to 2.5, and the diffuser efficiency did not increase with further increase in depth. Pressure distributions between ribs along the height of the rib showed that a pressure minimum existed in the grooves and gave evidence of strong vortex formation in the inter-rib spaces. Practically no difference in diffuser efficiency was observed for groove widths of 1 to 5 mm. The favorable effect of ribs decreased for groove widths greater than 5 mm which apparently was caused by the increased resistance to the flow over such a rib system. A relatively small number of ribs was required for obtaining the desired effect.

A preliminary investigation conducted at AEDC on a 40-deg conical diffuser with and without ribs verified that ribs do increase diffuser efficiency. However, this investigation was limited in Mach number and Reynolds number range, and the rib parameters were not varied. Therefore, a research test was conducted in the Propulsion Wind Tunnel Facility (PWT) in an attempt to investigate the mechanism by which ribs cause an increase in diffuser efficiency and to establish optimum rib parameters over a wide range of subsonic Mach number, Reynolds number, and diffuser opening angle. Also, a limited amount of data was obtained with vortex generators to compare the increase in diffuser efficiency with diffusers using transverse ribs.

SECTION II
APPARATUS

2.1 TEST FACILITY

This investigation was conducted in the Aerodynamic Wind Tunnel, Supersonic (1S). This wind tunnel is an open-circuit, continuous flow wind tunnel capable of operation at Mach numbers from 1.5 to 5.0. For this test, the test section, diffuser, and nozzle side plates were removed, and a liner was installed in the nozzle. This converted the tunnel to a subsonic test cell capable of operation at Mach numbers from 0.06 to 0.80 and at stagnation pressures from 200 to 5500 psf. A schematic of the tunnel test section showing the test unit installation is presented in Fig. 2. Further details of the facility can be found in Ref. 2.

2.2 TEST ARTICLE

The test unit (Fig. 3a) consisted of a bellmouth connected to a 4-in. square duct 44 in. long. A diffuser with one side expanded and with interchangeable flap and rib inserts was attached to the duct. The length of the test unit was dictated by the test cell. Each side of the diffuser was made of clear plastic with inserts of optically flat glass at the rib location to permit the use of the schlieren system to observe the flow over the ribs. The remainder of the test unit was constructed of aluminum. The rib inserts had groove depths (a) of 0.30, 0.40, and 0.50 in., and groove widths (b) of 0.08, 0.16, and 0.24 in. which gave values of a/b from 1.25 to 6.25. The vortex generators were designed in accordance with data from Ref. 3 and had NACA 0012 airfoil sections. Each vortex generator was mounted at an angle of attack of 15 deg. Further details of the vortex generators are shown in Fig. 3b.

2.3 INSTRUMENTATION

Static and total pressures were measured with a 100-tube, 120-in., water-filled manometer board and were recorded photographically. Each tube of the manometer board was connected to two orifices through a two-way switching valve to allow 200 pressures to be measured.

Seven static pressure orifices located in the side wall of the diffuser at the exit plane were manifolded together to obtain an average exit plane static pressure. A 1-psi differential pressure transducer was connected between the exit plane static pressure manifold and an

orifice located 28 in. upstream of the diffuser inlet to measure the static pressure rise through the diffuser.

Fluctuating pressures were measured with three close-coupled, high response transducers and a microphone. The transducers had a flat response from dc to 1250 cps, and the microphone had a flat response from 30 cps to 100 kc. Two of the transducers were located on the bottom of the ribbed insert with orifices in the bottoms of grooves 3 and 9 and were referenced to orifices on top of ribs 3 and 9. The third transducer was installed in the exit plane and was referenced to the exit plane manifold. Reference lead lengths of approximately 1 ft were selected to dampen any fluctuations in the reference pressure. The microphone was located in the diffuser side wall at the exit plane as shown in Fig. 4b. The outputs of the transducers and the microphone were monitored on an oscilloscope and were recorded on a direct reading oscillograph.

Total and static pressures at the diffuser inlet were measured with a retractable, traversing pitot-static probe. The probe was supported approximately 16 in. downstream of the diffuser exit and was designed for minimum thickness to reduce probe interference to the diffuser flow.

For the flow visualization part of the investigation, heated wires were installed in the diffuser inlet and on the traversing probe to allow the flow over the ribs to be observed with the schlieren system. The resulting flow patterns were recorded on color and black and white motion pictures and photographs.

Test conditions were set with reference to conditions 28 in. upstream of the diffuser inlet using a 100-in. mercury electromanometer to measure total pressure and an 80-in. mercury electromanometer to measure static pressure.

SECTION III
TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

Pressure data were obtained for each configuration at Mach numbers from 0.06 to 0.70 at Reynolds numbers from 10^5 to 1.6×10^6. The stagnation pressure varied from 200 to 5500 psf, and the stagnation temperature varied from 80 to 130°F. Up to $M_\infty = 0.30$, maximum Reynolds numbers were limited by the available air supply pressure of 5500 psf. Above $M_\infty = 0.30$, the maximum Reynolds numbers were limited by the

maximum allowable differential pressure on the manometer board and the pressure transducers. Minimum Reynolds numbers were limited by the accuracy with which Mach number could be set and by test cell leaks below 200 psf. The resulting Reynolds number variation with Mach number is presented in Fig. 5.

3.2 PRECISION OF MEASUREMENTS

The estimated precision of the data obtained during this test is as follows:

Mach Number

Re x 10^{-5}	$M_\infty = 0.06$	$M_\infty = 0.15$	$M_\infty = 0.30$	$M_\infty = 0.70$
1	±0.003	±0.004	±0.004	±0.005
3	±0.001	±0.002	±0.002	±0.002
5	-	±0.001	±0.001	±0.001
7	-	±0.001	±0.001	-
10	-	-	±0.001	-

Pressure Efficiency

Re x 10^{-5}	$M_\infty = 0.06$	$M_\infty = 0.15$	$M_\infty = 0.30$	$M_\infty = 0.70$
1	±0.06	±0.02	±0.009	-
3	±0.02	±0.01	±0.005	±0.001
5	-	±0.01	±0.004	±0.001
7	-	±0.01	±0.003	-
10	-	-	±0.001	-

The uncertainties quoted in the tables were determined by a statistical method based on a 95-percent confidence level and a normal error distribution (Ref. 4).

SECTION IV
RESULTS

The results presented in Ref. 1 for a flat diffuser model with one side expanded are summarized in Fig. 1. The range of groove depth, groove width, and number of ribs tested during the PWT investigation are indicated on Fig. 1 for comparison. Reference 1 gave no information pertaining to the Mach numbers and Reynolds numbers at which these tests were conducted.

During the test reported herein, the duct Mach number was set using a static pressure measured at a reference station 28 in. upstream of the diffuser inlet. The pressure efficiency is defined as the static pressure rise between the reference duct station and the exit plane of the diffuser, divided by the theoretical one-dimensional pressure rise through the diffuser.

The variations of pressure efficiency with Reynolds number and Mach number are presented in Figs. 6, 7, and 8, respectively, for diffuser opening angles of 16, 20, and 22 deg. Data obtained with a 24-deg ribbed diffuser showed that the ribs had no effect on diffuser efficiency because the flow was always separated at the diffuser inlet. Therefore, results for the 24-deg diffuser are not presented. In general, all other ribbed diffusers tested exhibited a higher pressure efficiency than the corresponding smooth diffuser for a particular Mach number and Reynolds number range, depending on rib geometry. For all rib geometries, none of the ribbed diffusers exhibited an increase in efficiency at Reynolds numbers equal to or less than that where the smooth diffuser exhibited complete separation. This appears to agree with the Ref. 1 observation that the ribs are effective only when the separation is downstream of the first groove.

In all instances, for Mach numbers less than about 0.4, the ribbed diffusers exhibited a small range of Reynolds numbers in which diffuser efficiency sharply increased to a maximum. For Mach numbers greater than 0.4 (Figs. 6, 7, and 8) the increase in diffuser efficiency with Reynolds number was much less, and in some cases for Mach number above 0.4, the smooth diffuser became more efficient than the ribbed diffuser.

The variations of pressure efficiency with the ratio of groove depth to groove width (a/b) for the 20-deg diffuser at Mach numbers 0.06 to 0.50 and high Reynolds number are presented in Fig. 9. For Mach numbers up to 0.30, the data indicate that the efficiency increased with increasing groove width and possibly with increasing groove depth; however, the change was small. Therefore, it is concluded that the ratio a/b is not critical as long as $a/b > 2$. Based on extrapolation of these results, it appears that an optimum rib configuration for the flat diffuser with one side expanded would have been a groove width of 0.25 in. and an a/b of about 5. For any diffuser configuration appreciably different from those investigated in this experiment, the optimum value of the parameter, b, should be determined experimentally and the groove depth chosen for maximum a/b up to about 6.

For comparison purposes, a limited amount of tests was conducted using vortex generators in the 20- and 22-deg diffusers. The results of

these tests are presented in Fig. 10. The effects of size and location of the vortex generators were investigated in the 22-deg diffuser. Vortex generator configuration 2 exhibited the greatest efficiency in the 22-deg diffuser, and this configuration was then tested in the 20-deg diffuser. In general, the vortex generators caused an increase in efficiency at Reynolds numbers below those at which the ribbed diffuser first became effective, but the vortex generators did not increase the efficiency as much as the ribbed diffuser at the higher Reynolds numbers. The vortex generators exhibited a gradual decrease in efficiency with increasing Mach number and a gradual increase in efficiency with increasing Reynolds number, as did the smooth diffusers; whereas the ribbed diffusers correspondingly exhibited an abrupt decrease to zero efficiency at some Mach number between 0.3 to 0.6, and a relatively constant efficiency with increasing Reynolds number.

The variation of diffuser efficiency with diffuser angle is presented in Fig. 11 for the smooth diffuser, the diffuser with vortex generators, and the diffuser with ribs 3 and 8 at M_∞ = 0.06, 0.15, 0.30, and 0.50. The variations of η_{vg}/η_s and η_r/η_s with diffuser angle are presented in Fig. 12 for comparison purposes. As mentioned earlier, the 24-deg diffuser remained completely separated for all rib configurations, Mach numbers, and Reynolds numbers. Therefore, the curves in Fig. 11 for ribs 3 and 8 are extrapolated to zero efficiency between θ = 22 and 24 deg when the efficiency did not become zero before θ = 22 deg. Comparisons of the data obtained with the smooth diffuser with that of the ribbed diffuser indicate that the ribs increased the efficiency considerably for diffuser angles in the range of 20 to 22 deg at high Reynolds numbers. For the 16-deg diffuser, the smaller groove width (rib 3) caused a slight increase in efficiency, whereas the larger groove width had only small effects on efficiency. Reference 1 explains this as a decrease in the intensity or extent of flow separation in a smooth diffuser with decreasing diffuser opening angle. Therefore, by the argument of Ref. 1, at θ = 16 deg, the losses caused by small-scale separation and by flow over the ribs become equal to the losses caused by the large-scale separation, and the ribs have practically no effect on efficiency. The practical use of ribbed diffusers would appear to be limited to angles of roughly θ = 18 to 22 deg where a maximum increase in efficiency is prevalent. In this range, the ribbed diffuser exhibited increases in efficiency greater than a factor of 2. The diffuser with vortex generators did not exhibit as high an increase in efficiency as the ribbed diffuser at high Reynolds numbers. However, the diffuser with vortex generators exhibited higher efficiencies at the lower Reynolds numbers, where the ribbed diffuser was ineffective.

Several attempts were made to study the mechanism by which transverse ribs cause an increase in diffuser efficiency. From visual

observation using the schlieren system in conjunction with heated wires, the flow over the ribbed section was observed to be either attached to the expanded wall over the entire length of the ribbed section or separated at the inlet of the diffuser. At very low Reynolds numbers, the flow was separated for the diffusers with θ = 20 and 22 deg. As the Reynolds number was increased, a point was reached at which the flow would occasionally attach to the expanded wall for a short period of time. As the Reynolds number was further increased, the flow would remain attached for longer periods of time until the Reynolds number became high enough for the flow to remain permanently attached to the expanded wall.

Reference 1 was somewhat vague as to the details of the vortex system. It is well known that a vortex will form in a slot or groove when flow is established over the surface (Ref. 5). The schlieren system was used in an effort to investigate the vortex system; however, no evidence of a vortex system in the vicinity of transverse ribs could be found.

Reference 1 stated that the ribs could emit "acoustic waves" when "the frequency of vortex decay at the end of the fin coincides with the natural frequency of air vibrations inside the interfin spaces." Three high-response transducers and a microphone were used in an attempt to measure any pressure fluctuations or noise in the diffuser; however, no evidence of the acoustic wave phenomena could be found. The pressure variations and noise were extremely small unless the flow was separated from the expanded wall.

SECTION V
CONCLUSIONS

The following conclusions have been drawn from the results obtained:

1. Ribs significantly improved the efficiency of a one side expanded, wide angle diffuser in the wall angle range of 16 to 22 deg except at low Reynolds numbers and at diffuser inlet Mach number in excess of about 0.4.

2. The exact size of the grooves did not appear to be critical. The data indicated that the grooves should have a depth-to-width ratio of 2 to 6, and the groove width should be varied to obtain maximum efficiency.

3. The ribs were found to be more efficient than the vortex generators tested except at low Reynolds numbers for all Mach numbers and at high Mach numbers for all Reynolds numbers.

REFERENCES

1. AID Report T-63-8. "Diffusers with Transverse Fins (Translations and Excerpts)." Aerospace Information Division, Library of Congress, 14 January 1963.

2. Test Facilities Handbook (5th Edition). "Propulsion Wind Tunnel Facility, Vol. 3." Arnold Engineering Development Center, July 1963.

3. Taylor, H. D. "Summary Report on Vortex Generators." Report R-05280-9, United Aircraft Corporation Research Department, March 1950.

4. Dean, Robert C., Jr. "Aerodynamic Measurements." Gas Turbine Laboratory, Massachusetts, 1953.

5. Roshko, Anatol. "Some Measurements of Flow in a Rectangular Cutout." NACA TN 3488, August 1955.

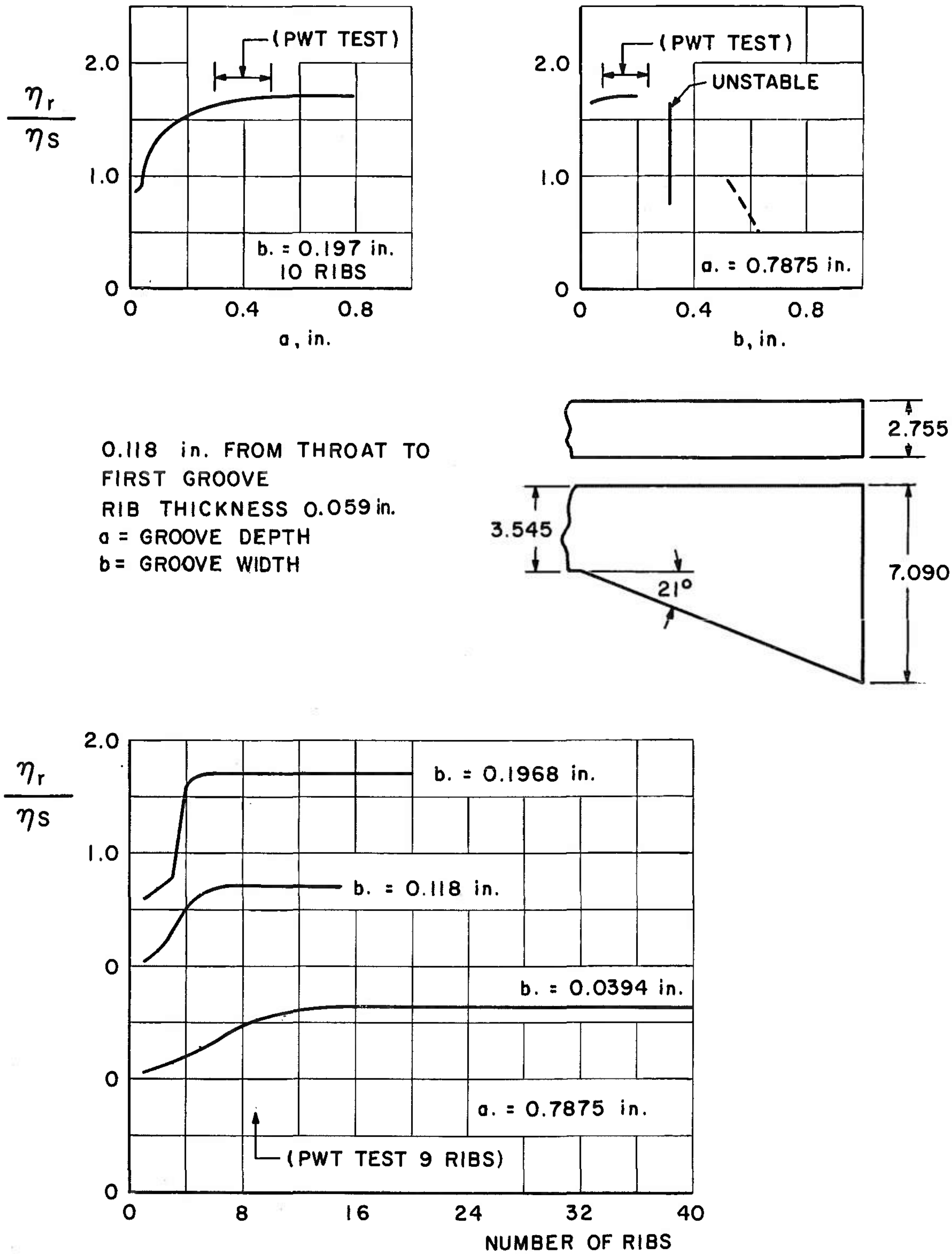


Fig. 1 Single Side Expanded Diffuser (Summary of Data Obtained from Ref. 1)

NOTE: TEST SECTION WALLS, SUPERSONIC DIFFUSER, AND NOZZLE SIDE PLATES AFT OF STA. -38.6 REMOVED. FLEXIBLE NOZZLE SET TO M = 1.5 CONTOUR.

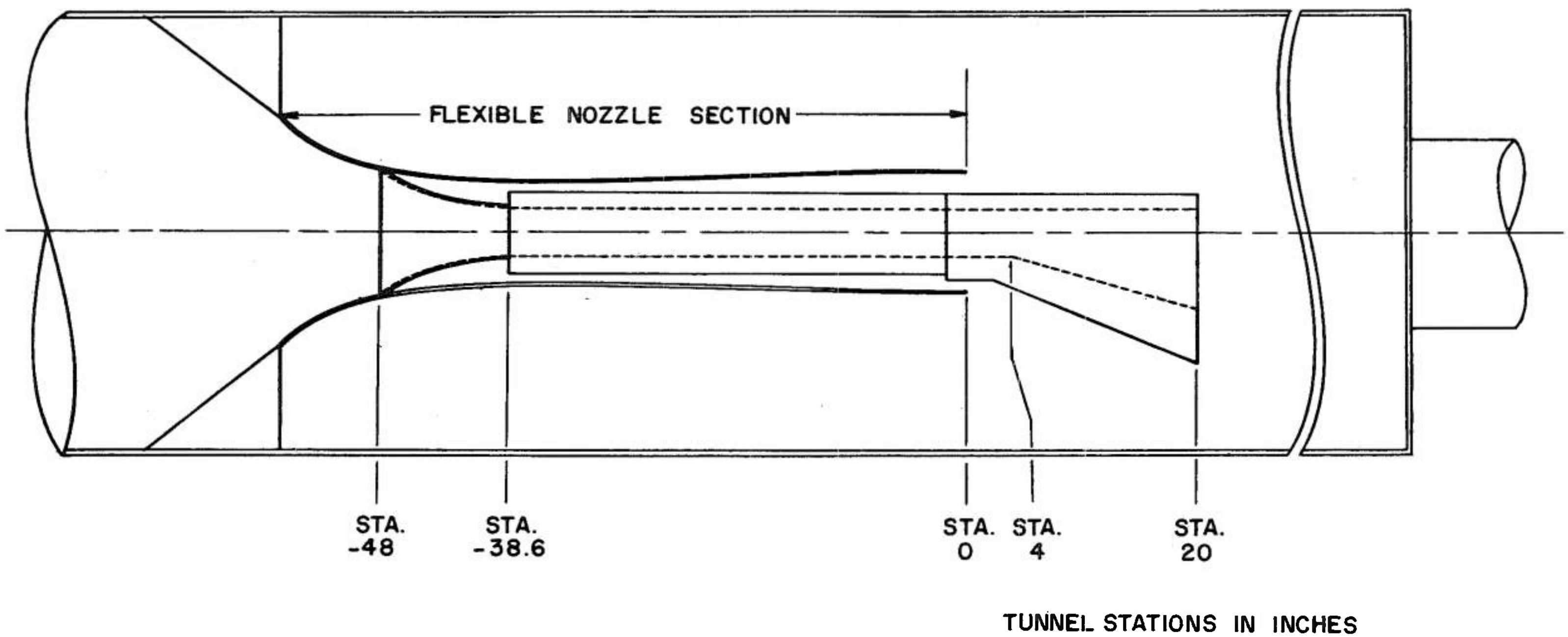
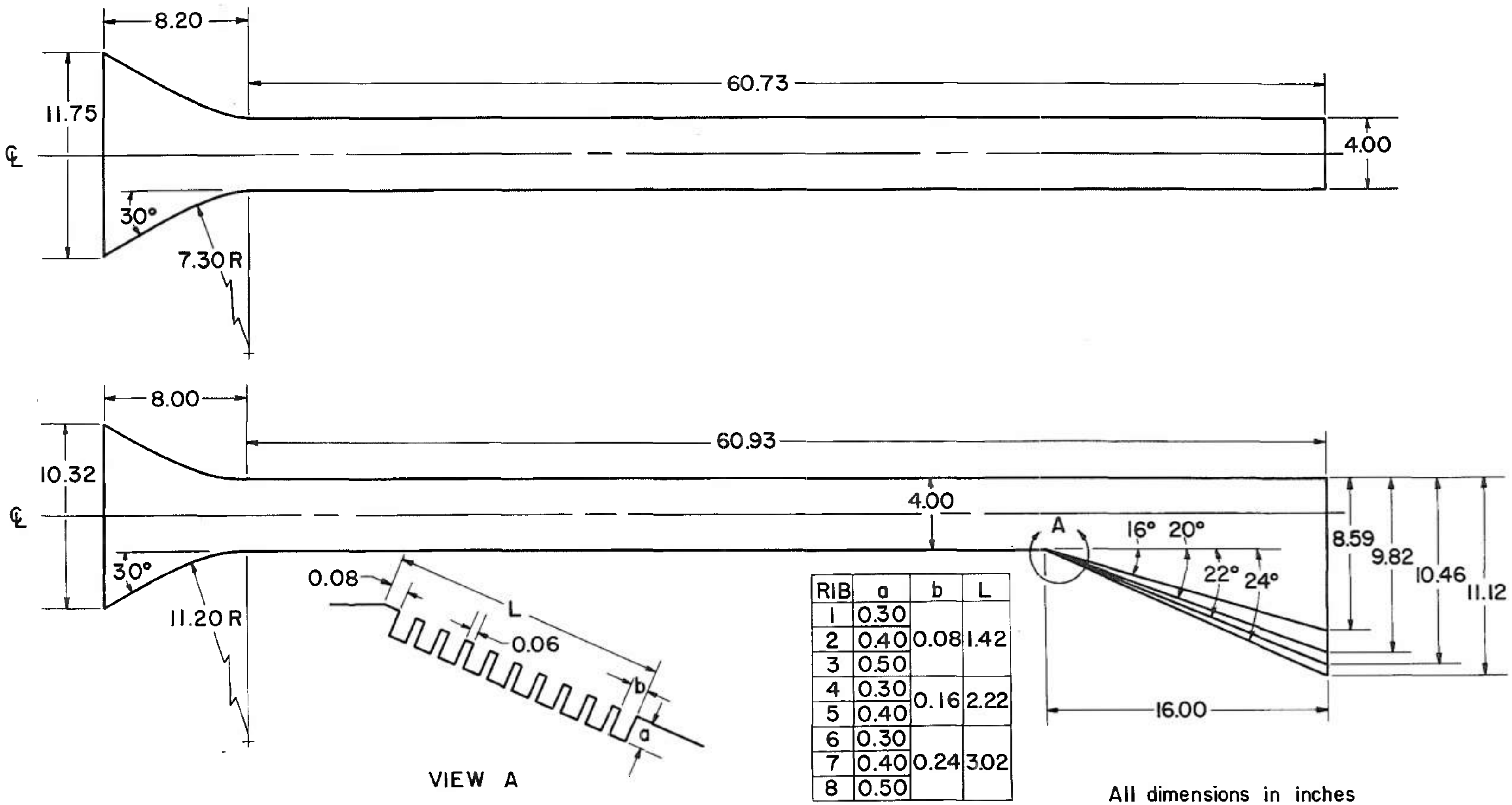


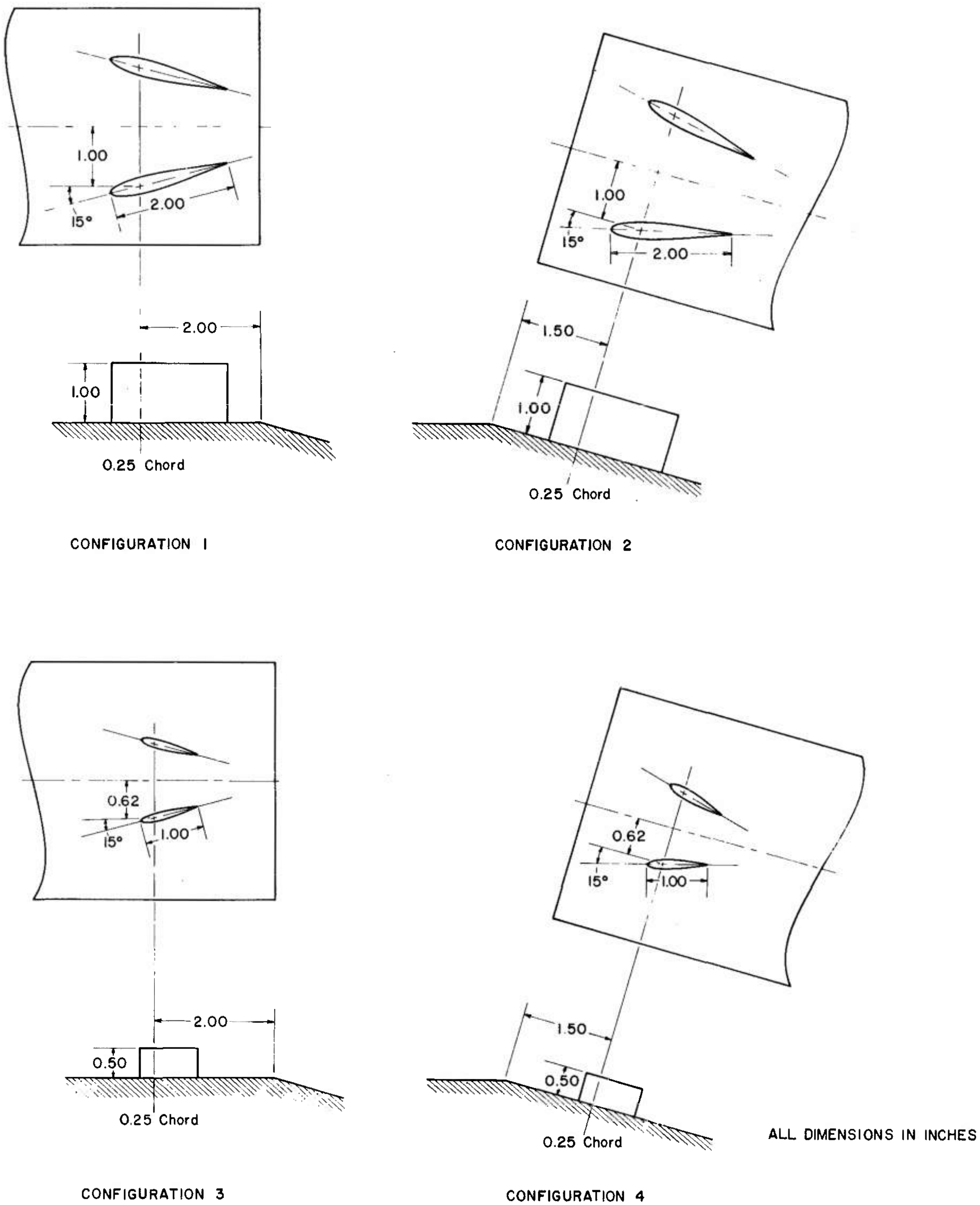
Fig. 2 Schematic of Test Cell and Test Unit Installation



RIB	a	b	L
1	0.30		
2	0.40	0.08	1.42
3	0.50		
4	0.30	0.16	2.22
5	0.40		
6	0.30		
7	0.40	0.24	3.02
8	0.50		

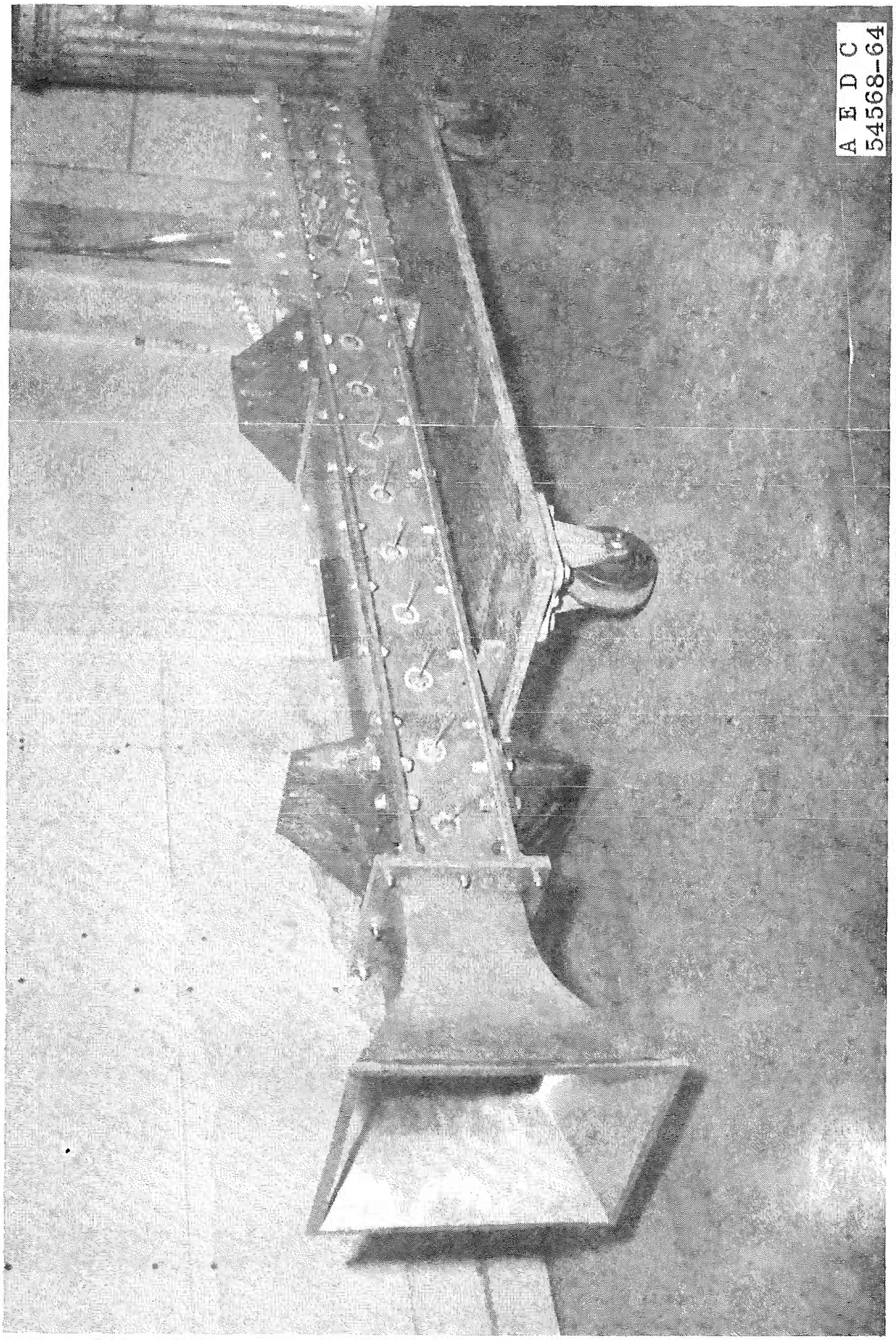
a. Test Unit and Ribs

Fig. 3 Test Unit Details and Dimensions



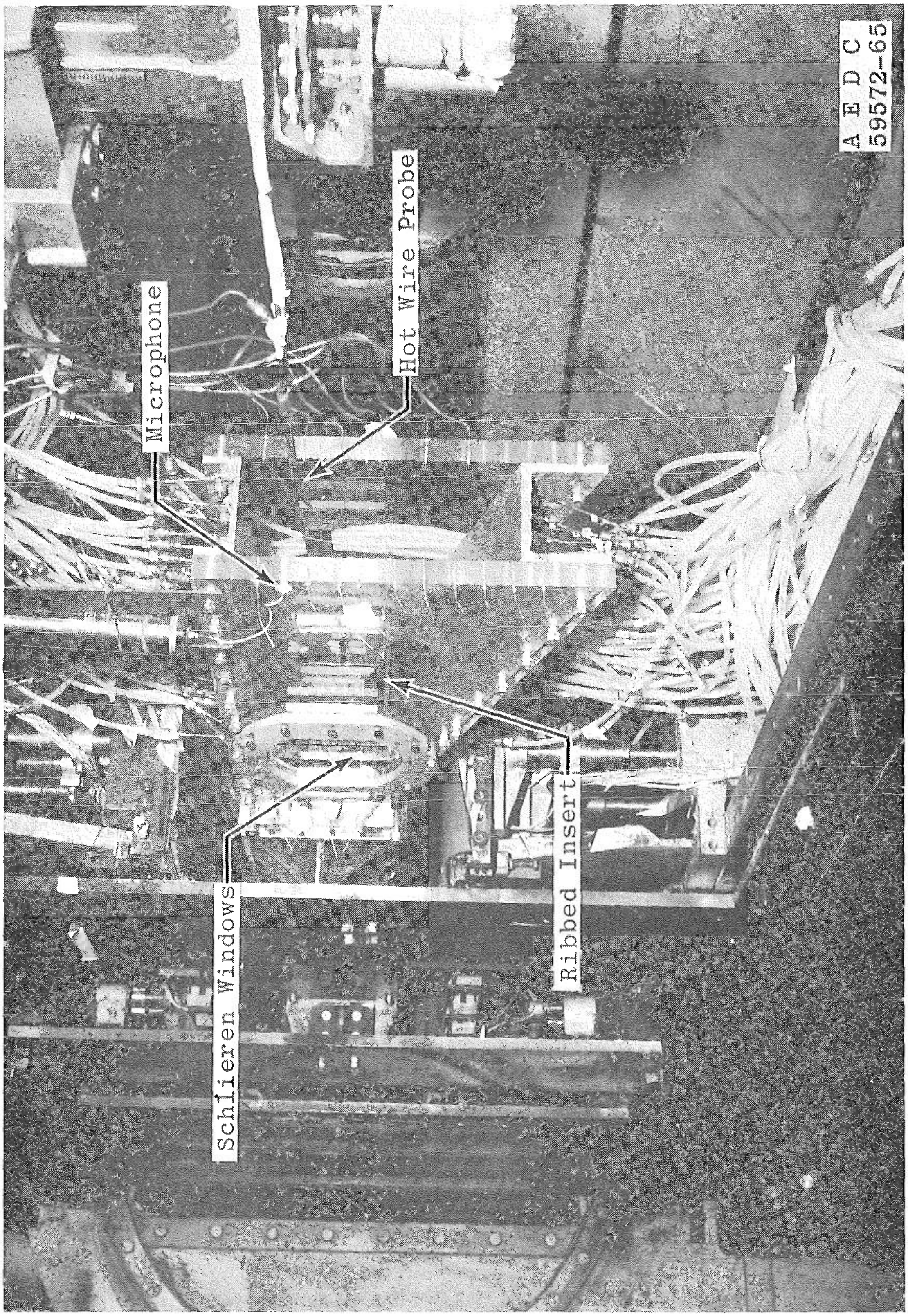
b. Vortex Generators

Fig. 3 Concluded



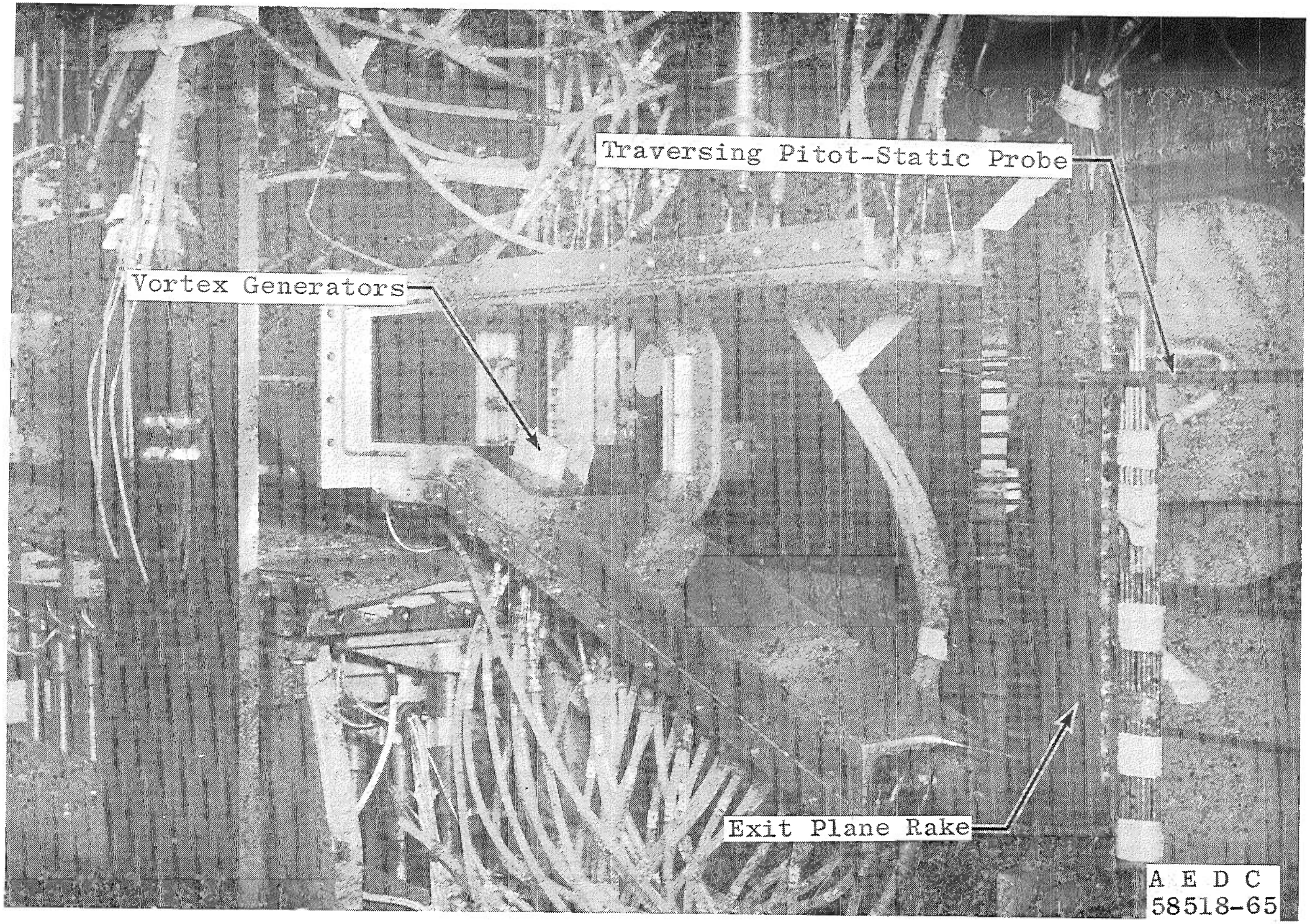
a. Test Unit before Installation

Fig. 4 Photographs of Test Unit



b. Test Unit Installed in Test Cell

Fig. 4 Continued



c. Vortex Generators (Configuration 2)

Fig. 4 Concluded

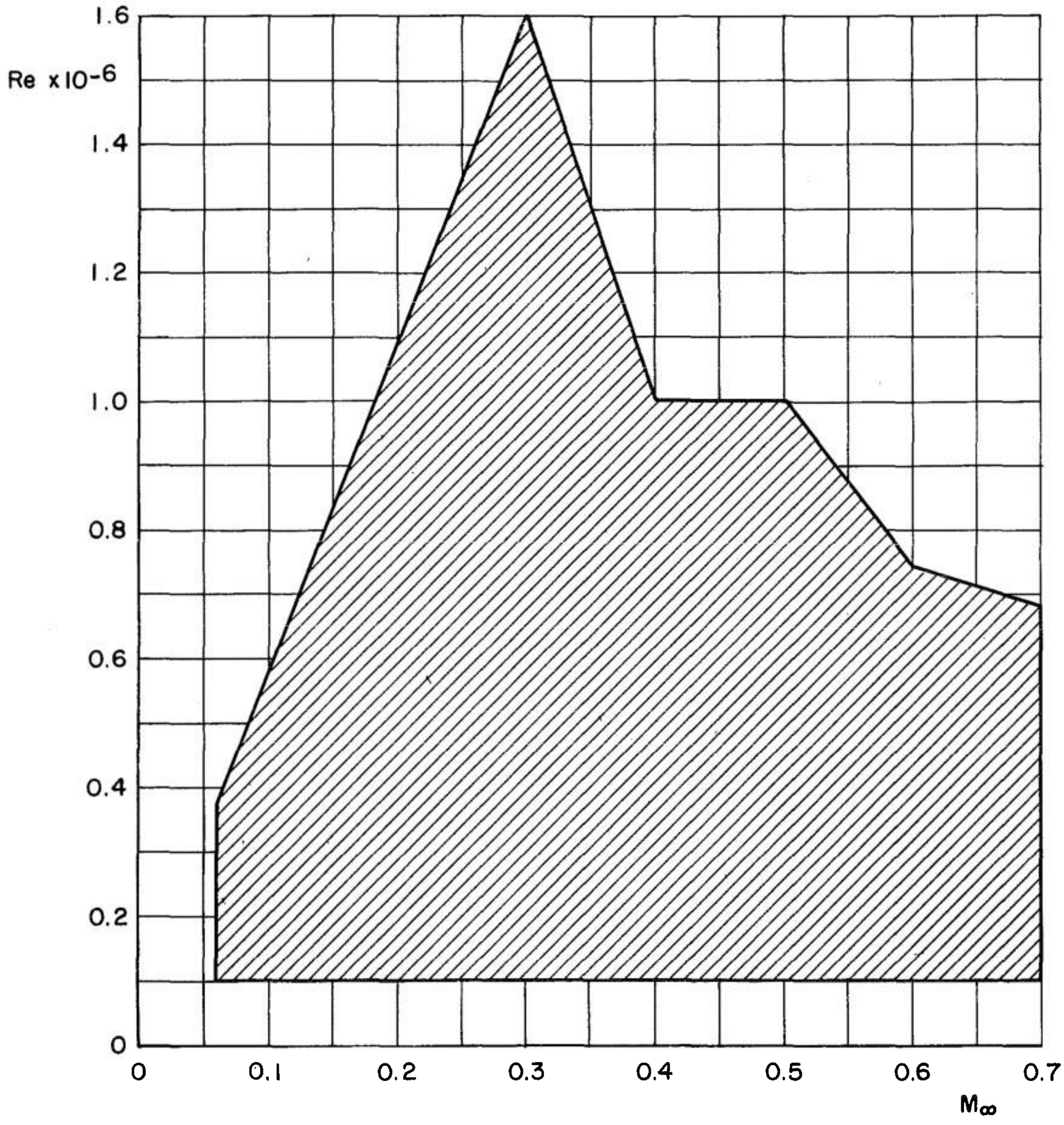
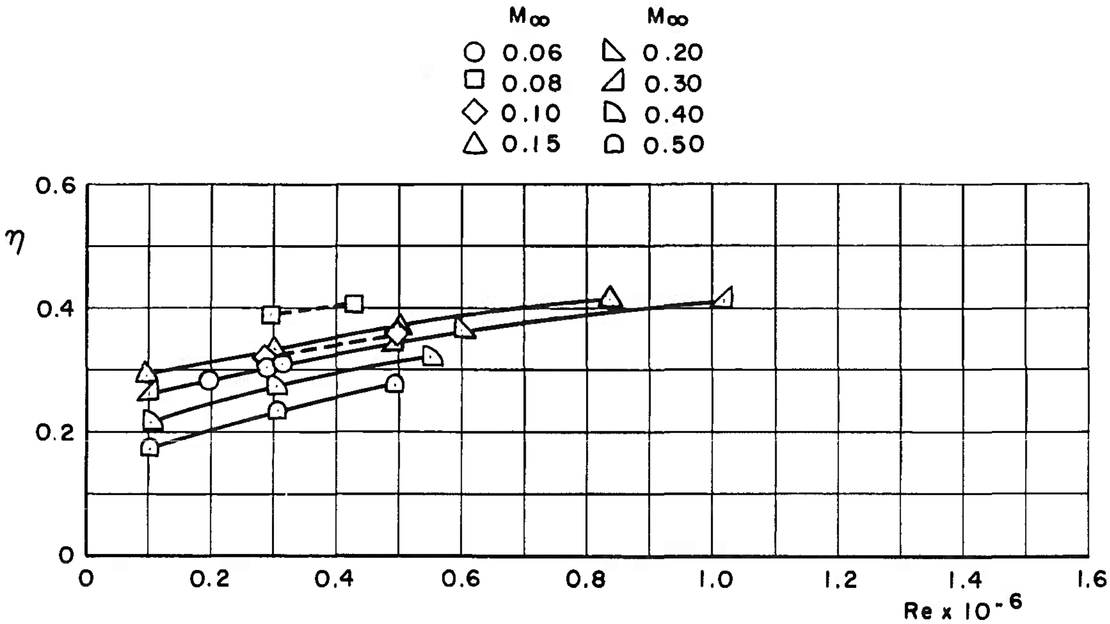
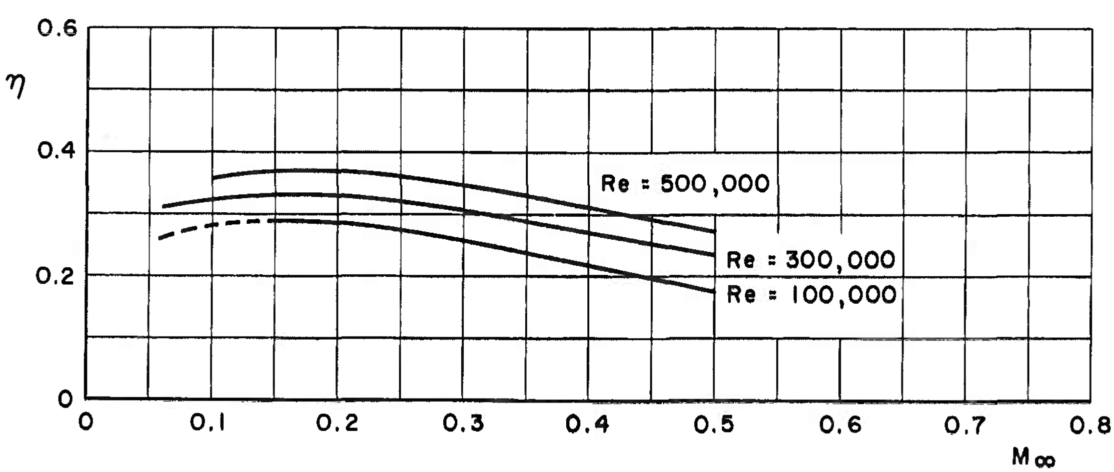


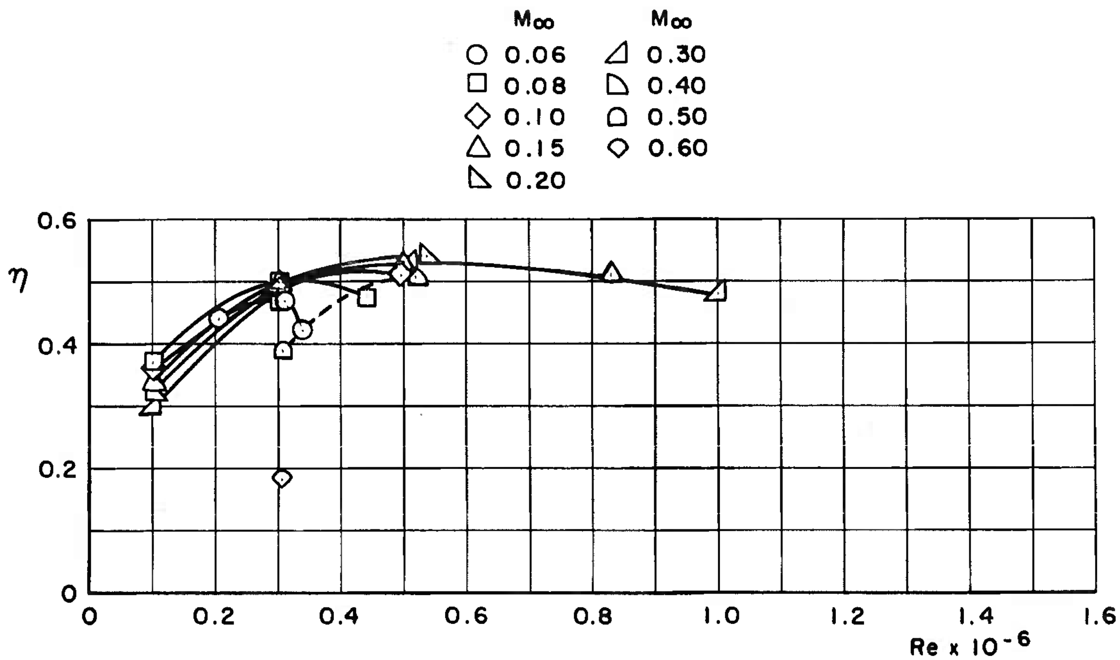
Fig. 5 Variation of Reynolds Number with Mach Number

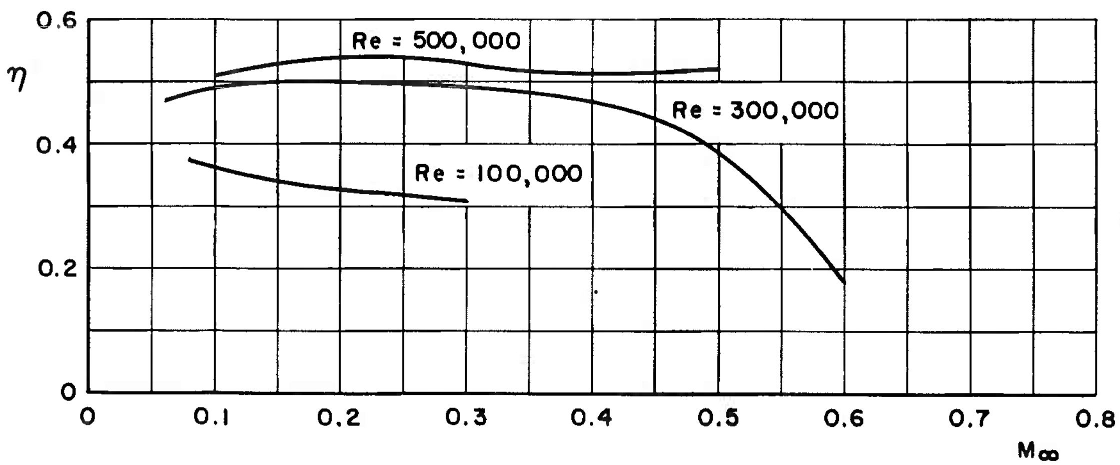




a. Smooth

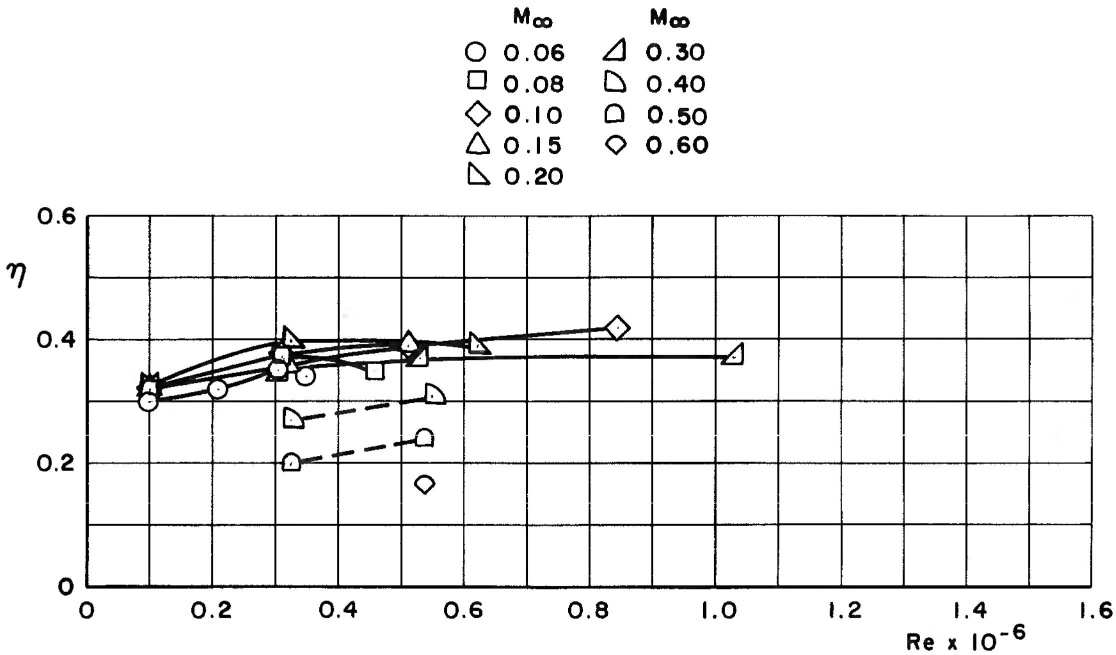
Fig. 6 Variation of Pressure Efficiency with Reynolds Number and Mach Number for the 16-deg Diffuser with and without Ribs

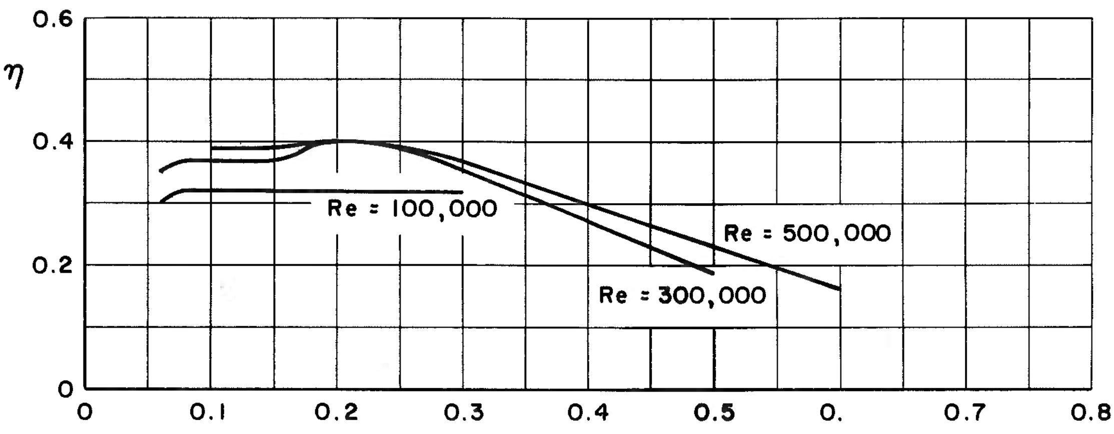




b. Configuration 3

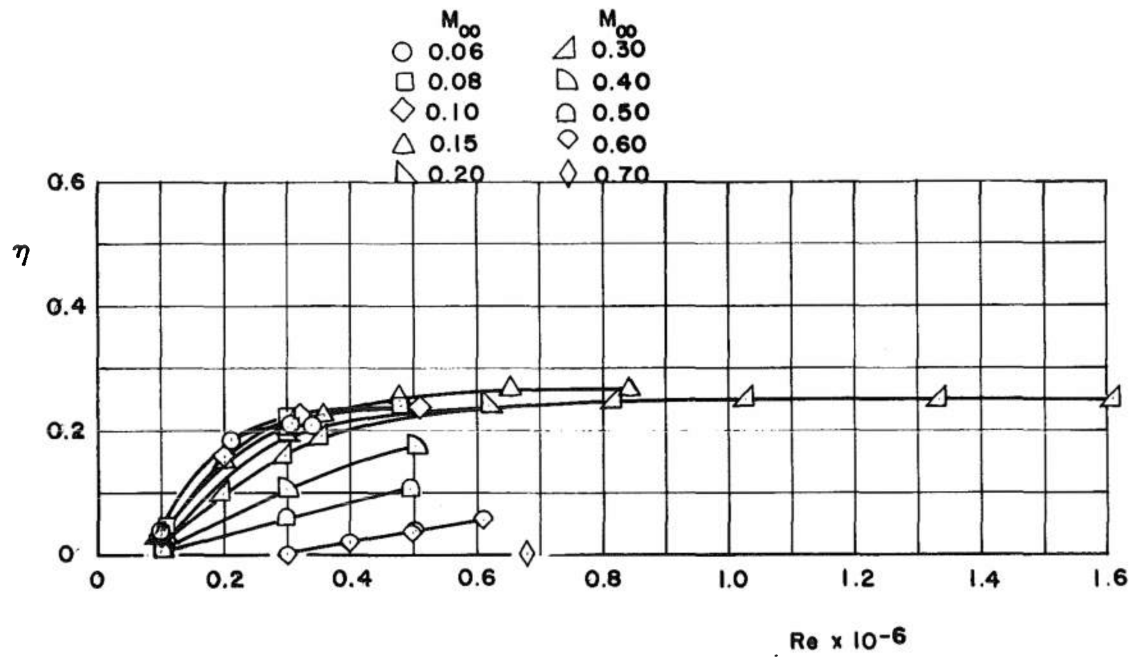
Fig. 6 Continued

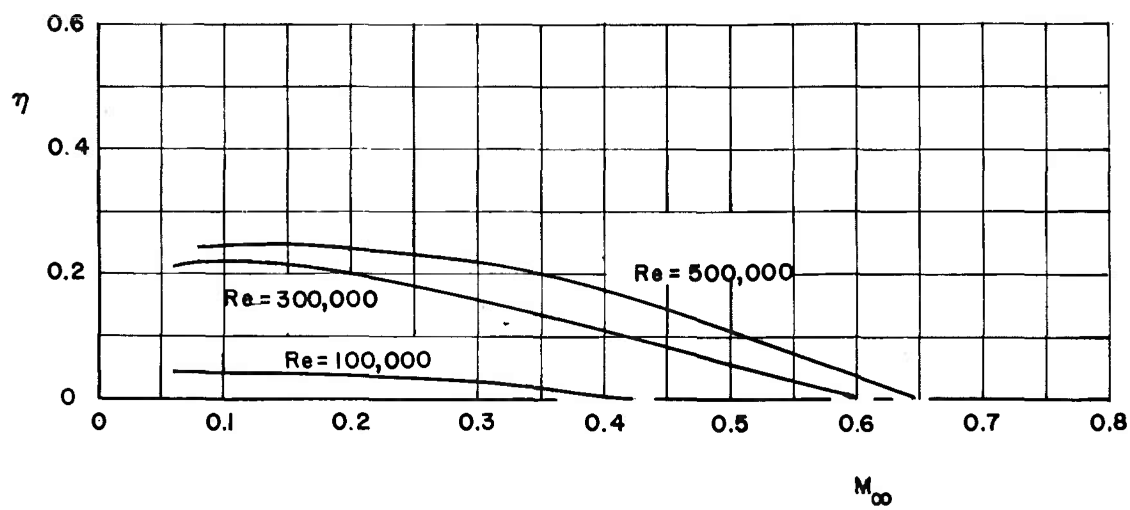




c. Configuration 8

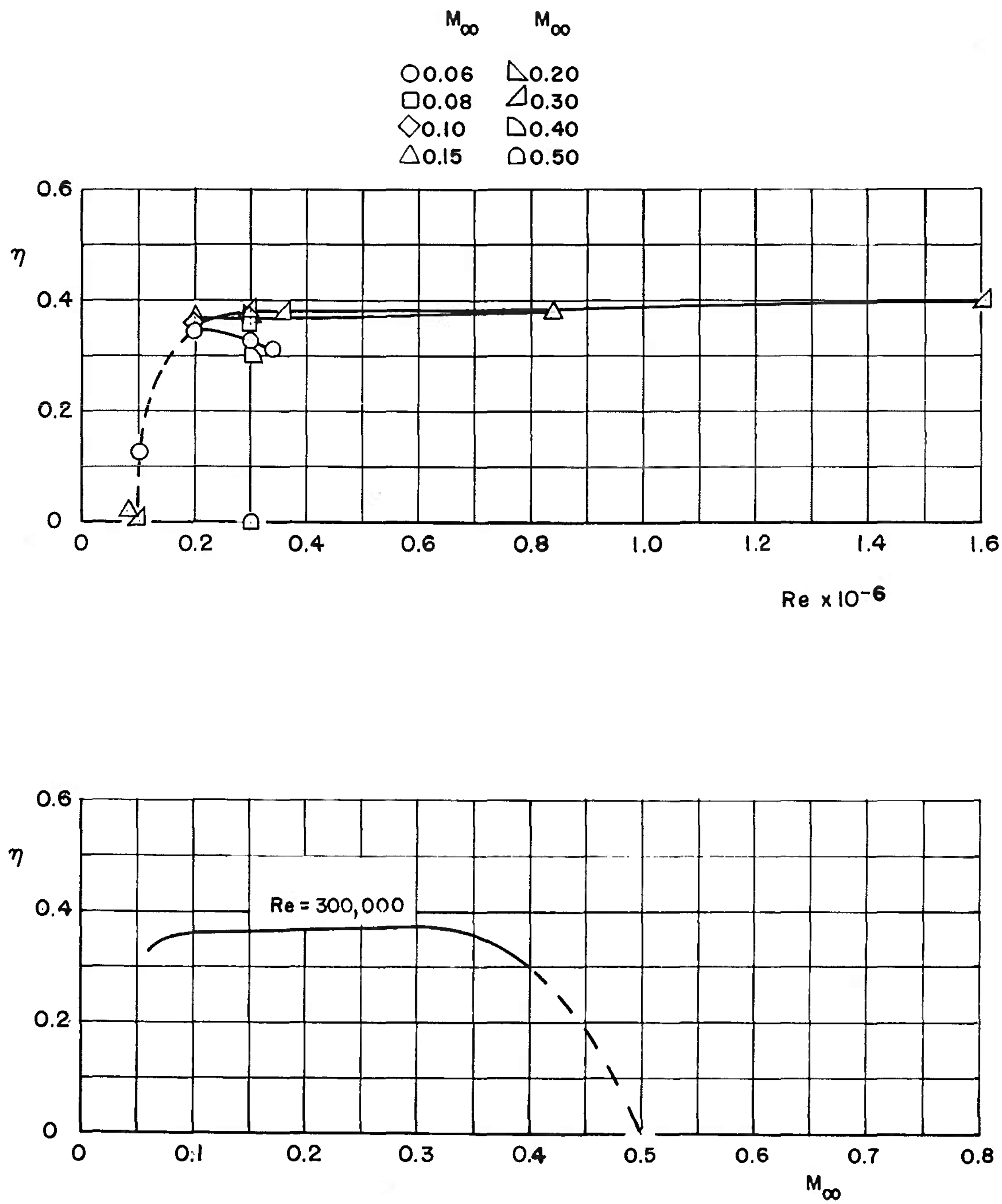
Fig. 6 Concluded





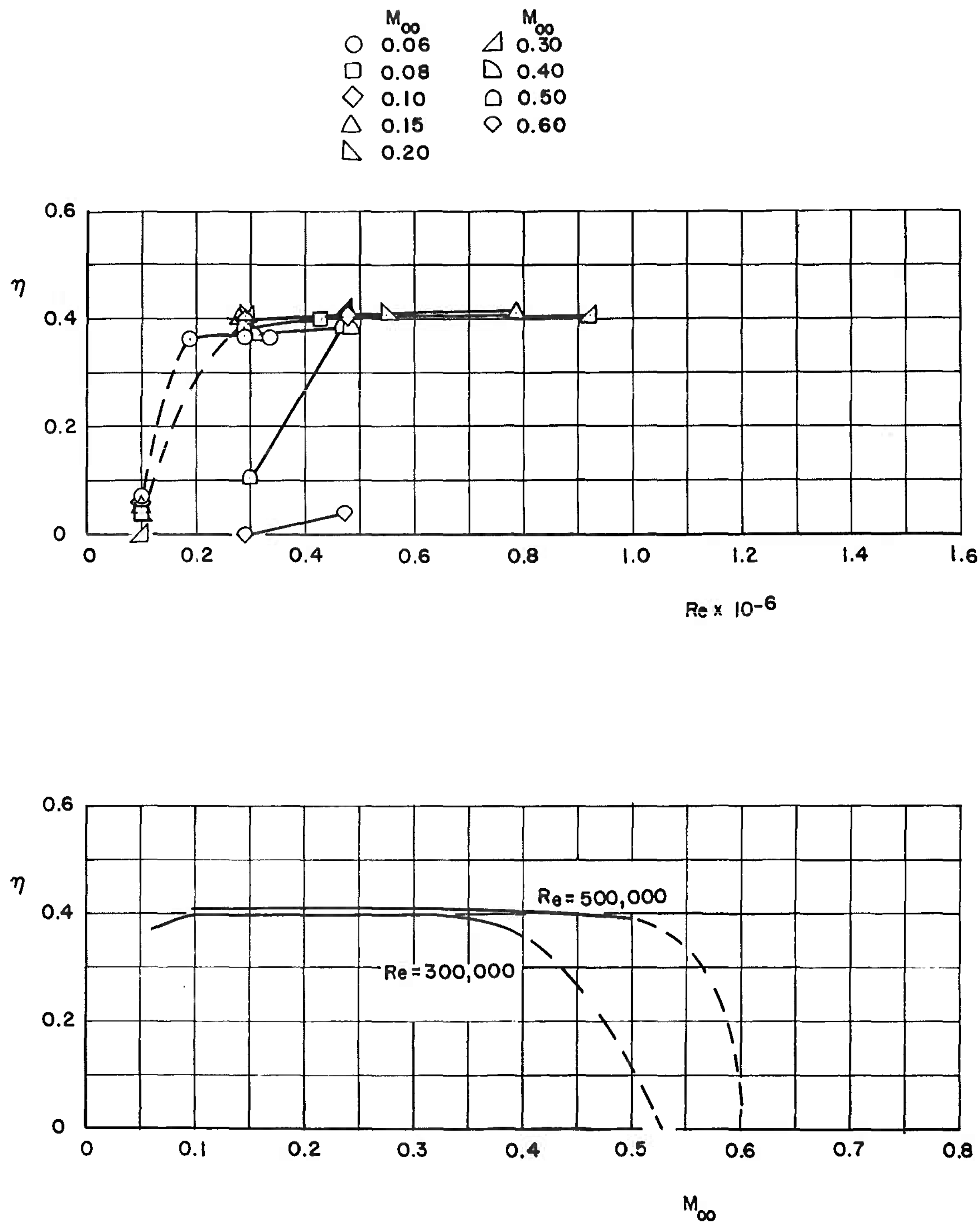
a. Smooth

Fig. 7 Variation of Pressure Efficiency with Reynolds Number and Mach Number for the 20-deg Diffuser with and without Ribs



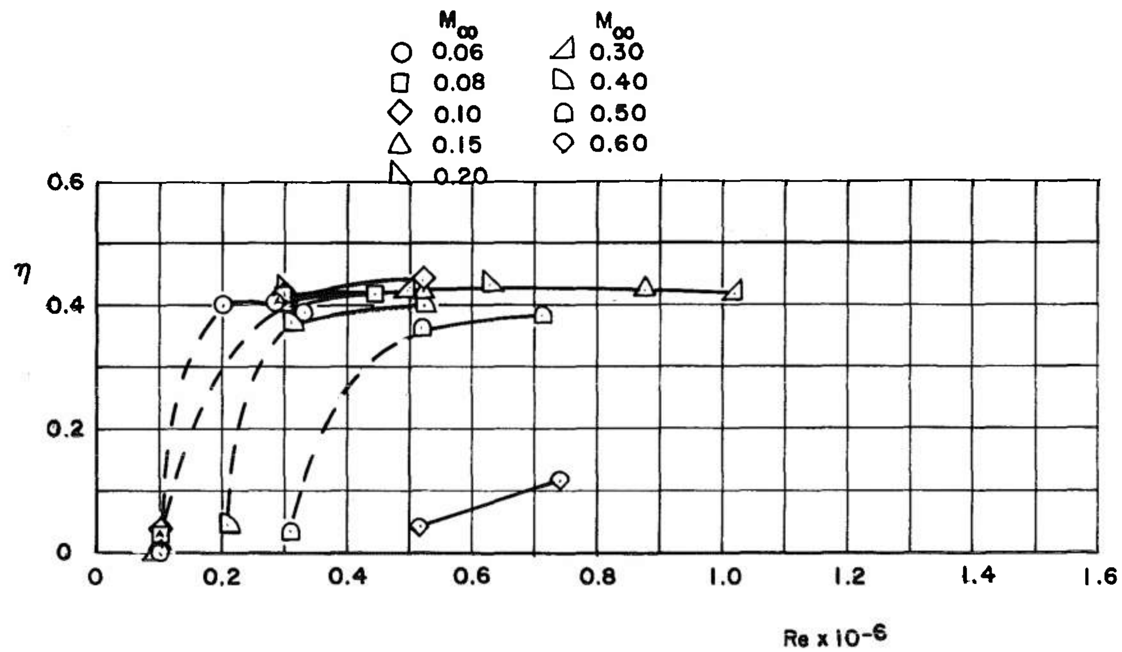
b. Configuration 1

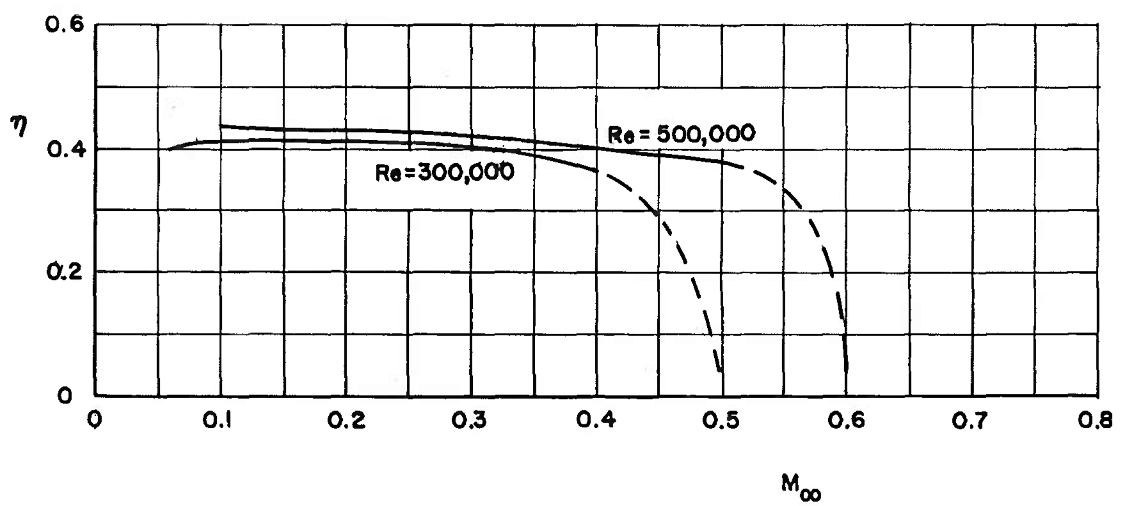
Fig. 7 Continued



c. Configuration 2

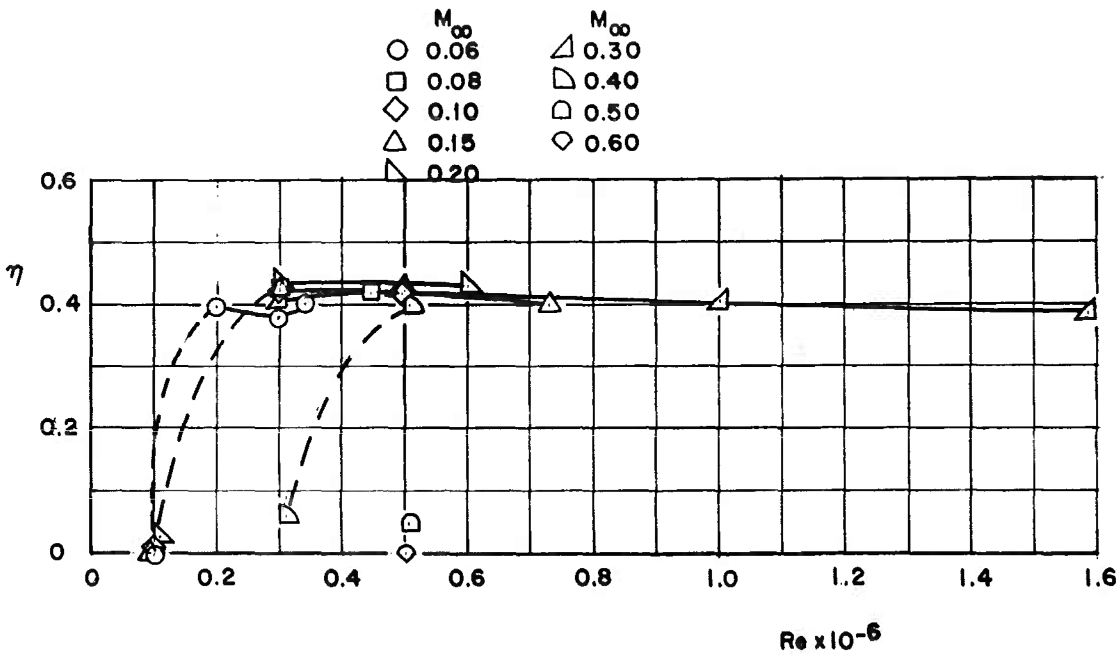
Fig. 7 Continued

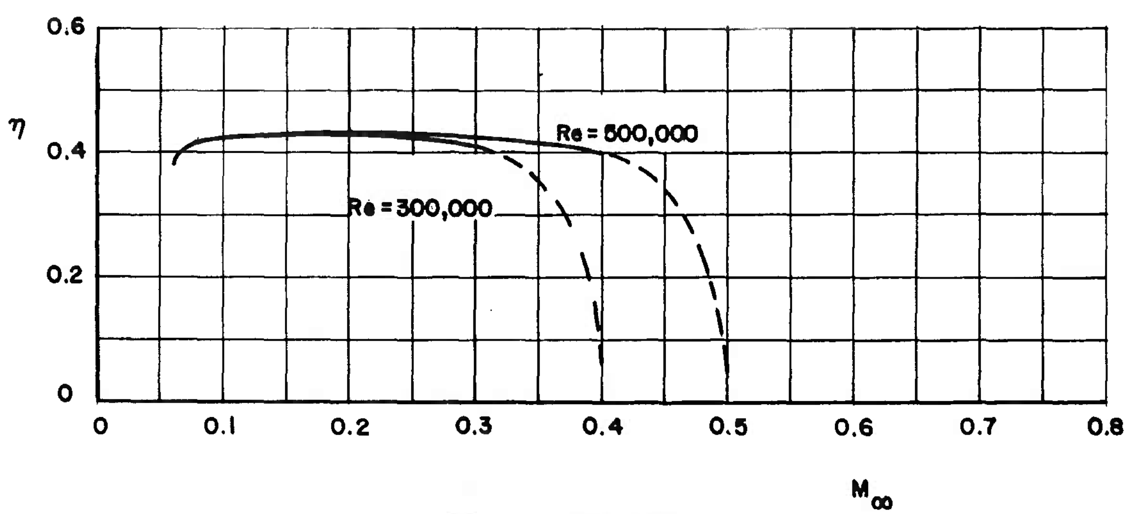




d. Configuration 3

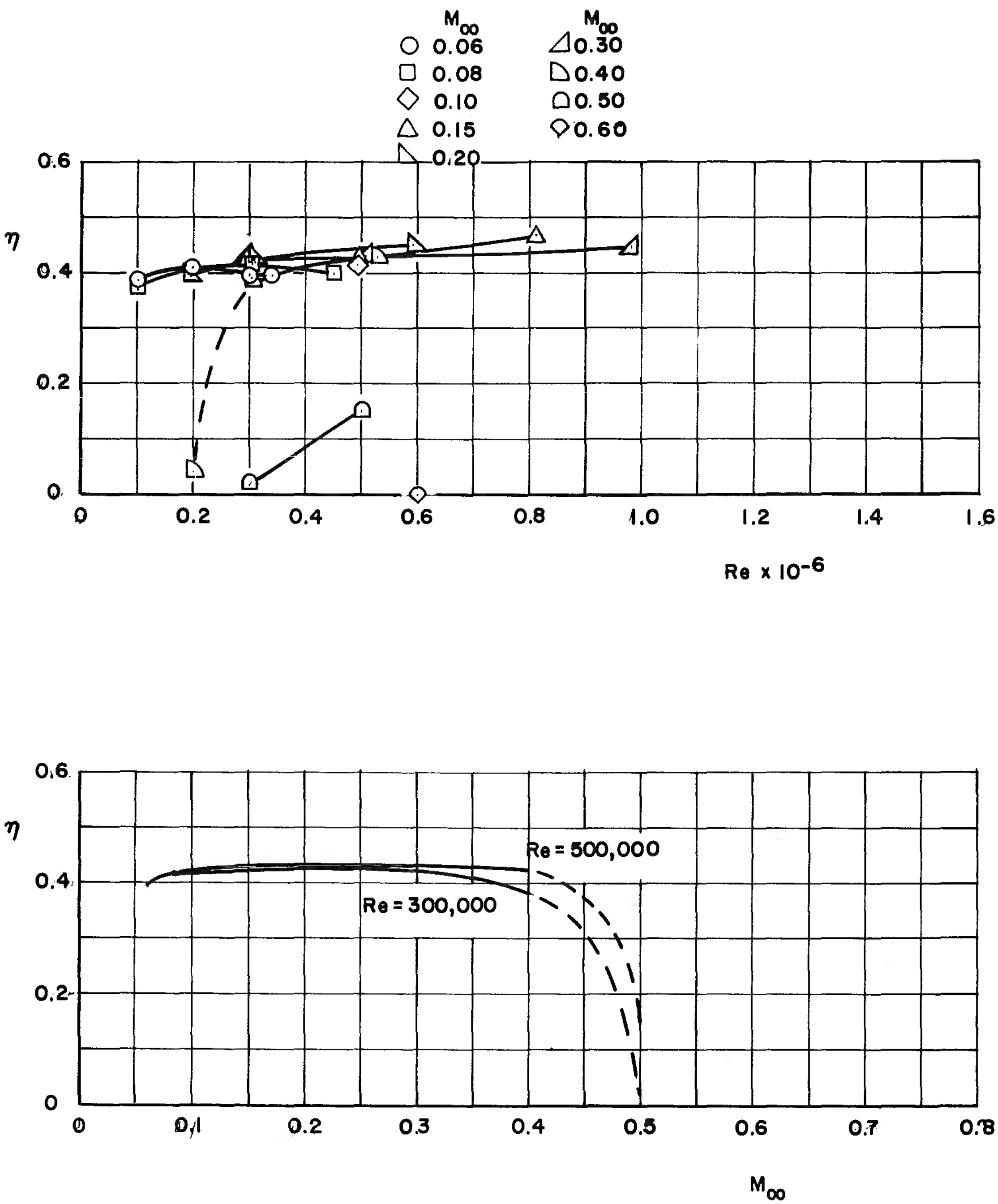
Fig. 7 Continued





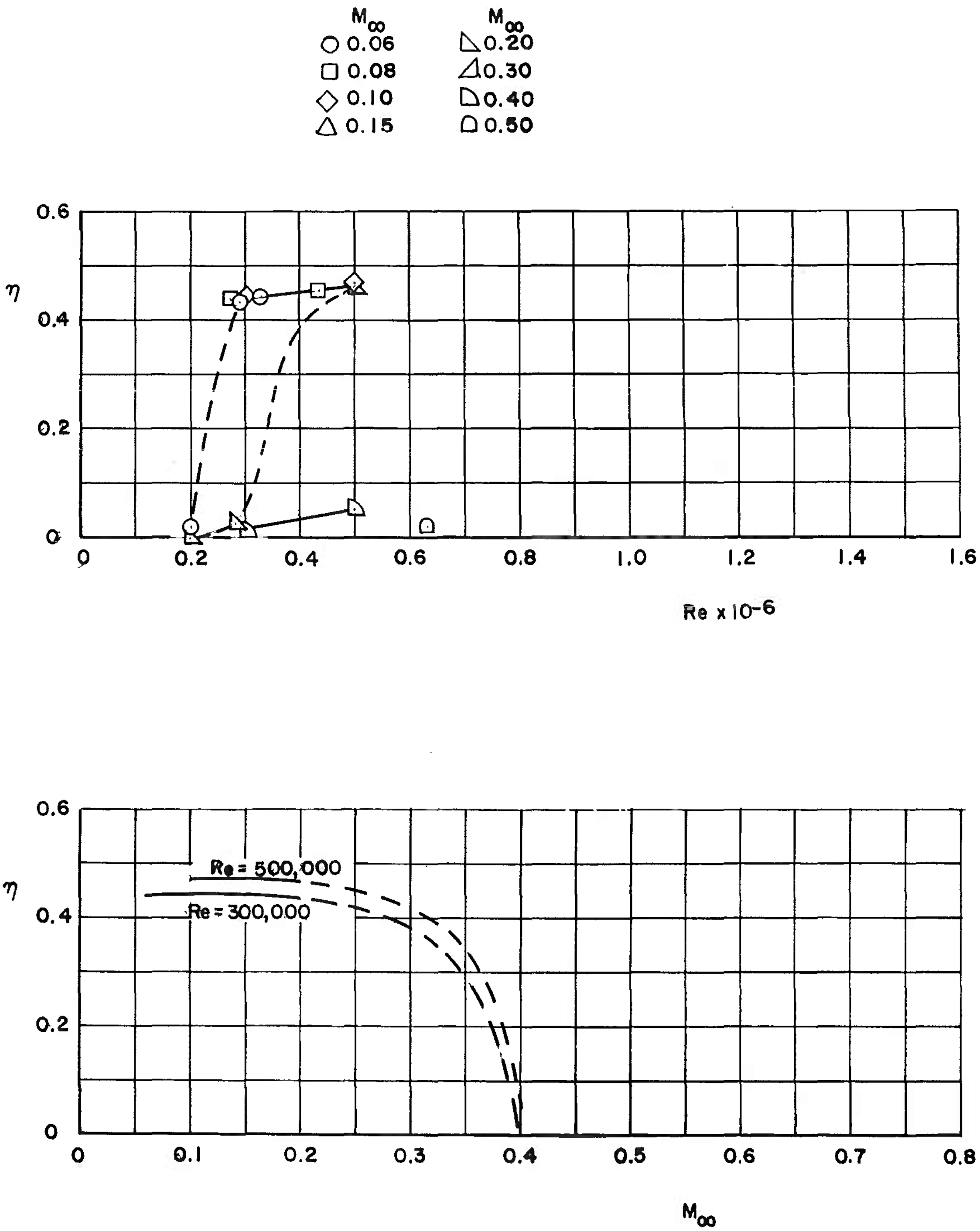
e. Configuration 4

Fig. 7 Continued



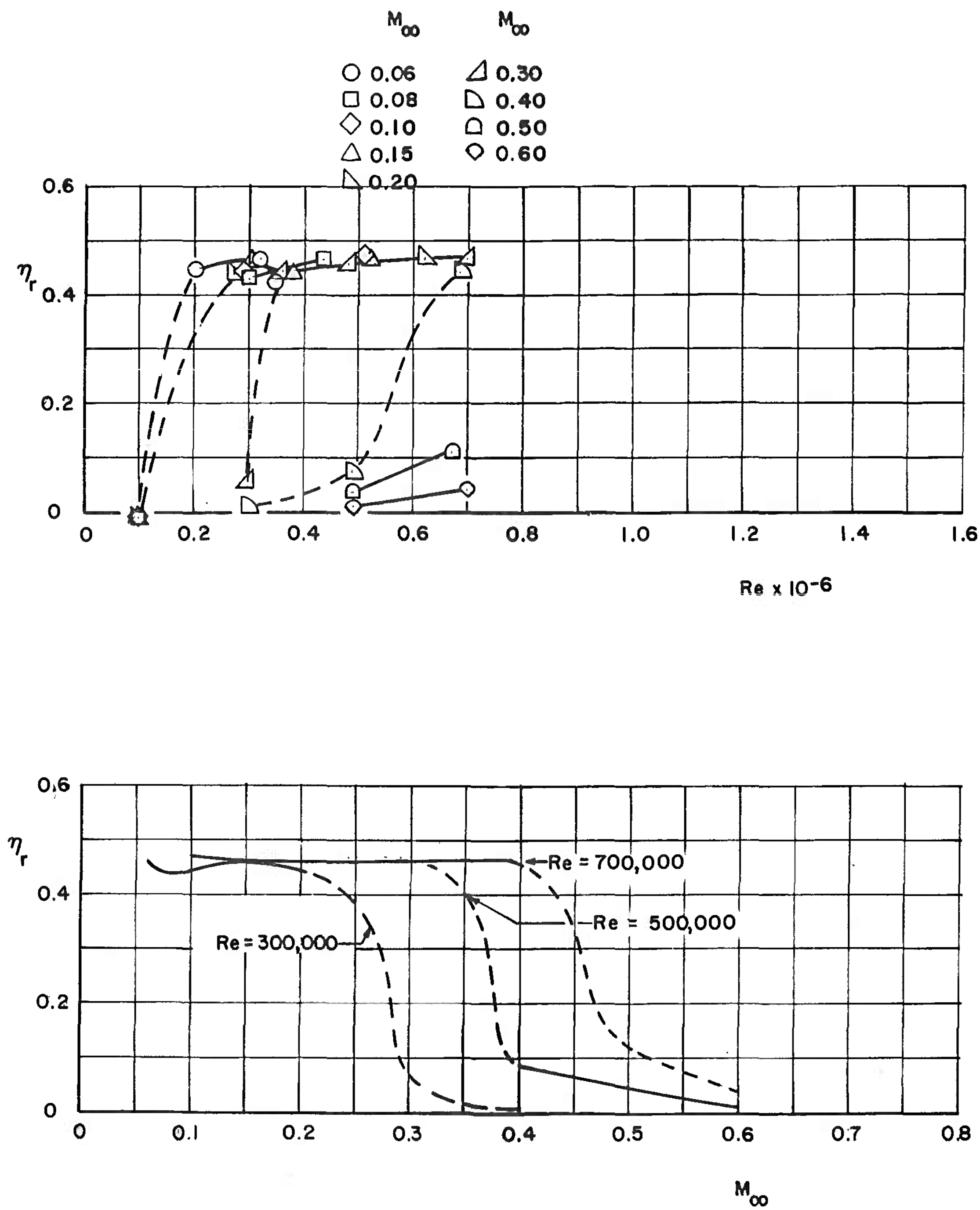
f. Configuration 5

Fig. 7 Continued



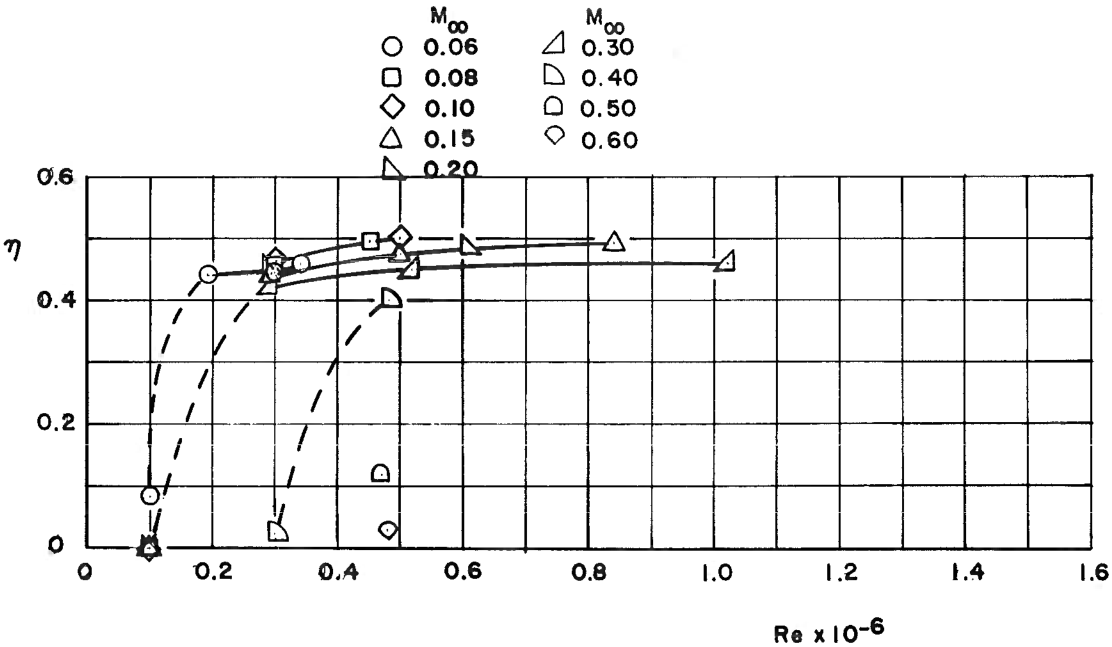
g. Configuration 6

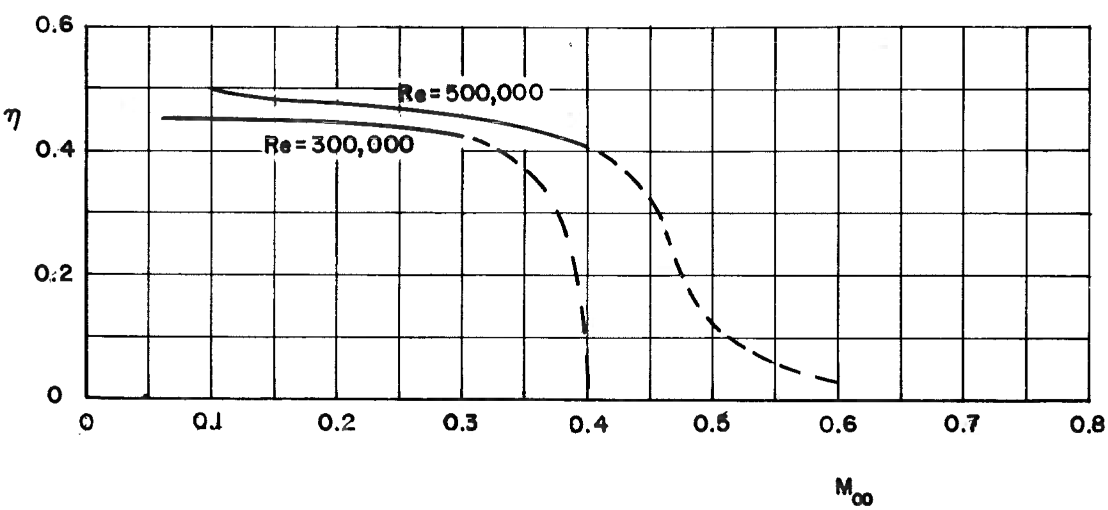
Fig. 7 Continued



h. Configuration 7

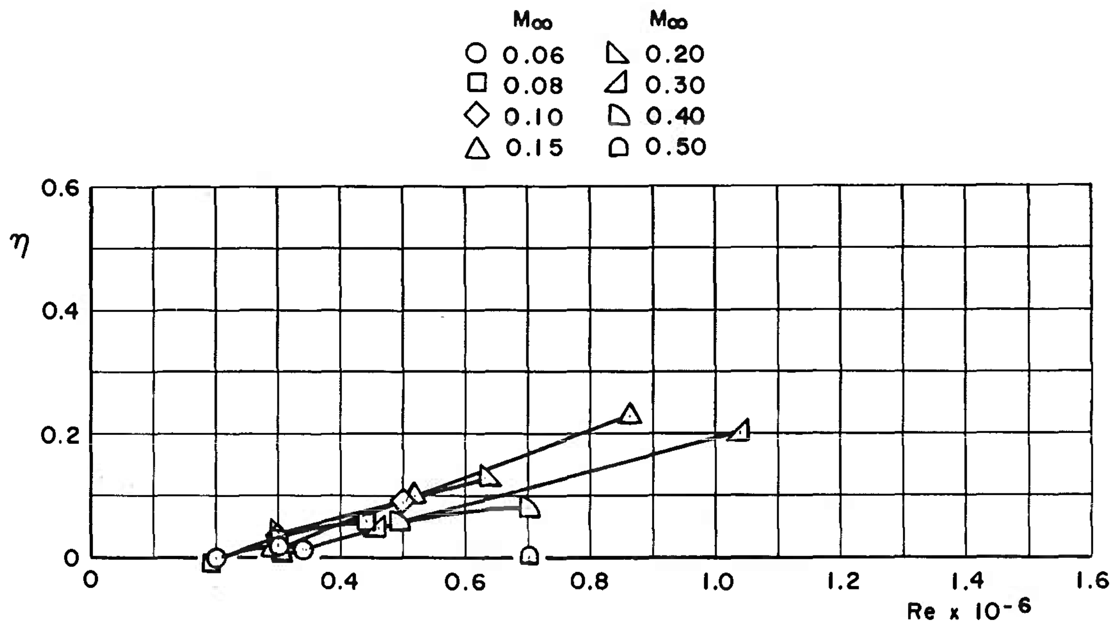
Fig. 7 Continued

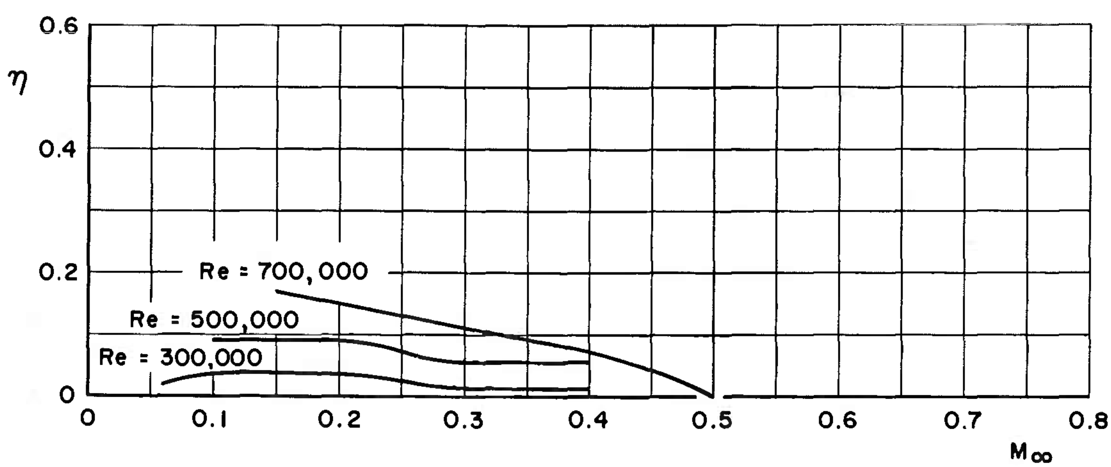




i. Configuration 8

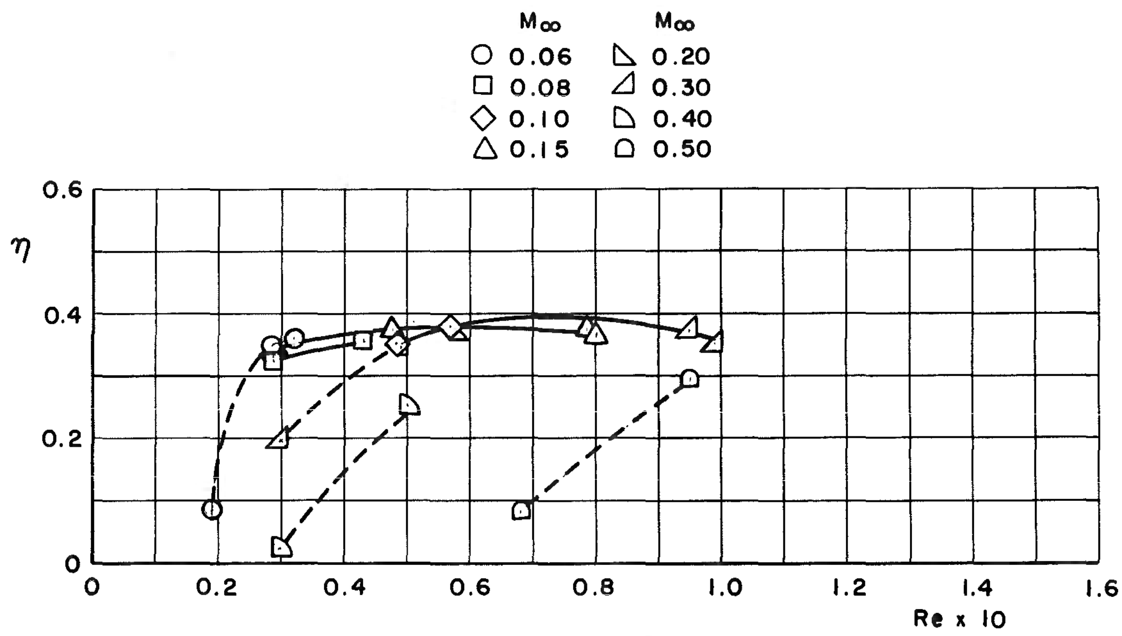
Fig. 7 Concluded

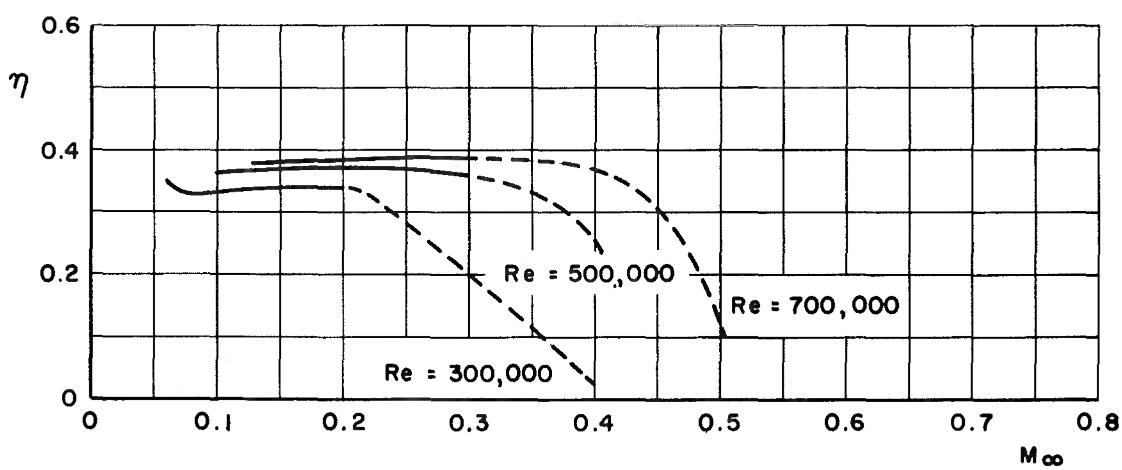




a. Smooth

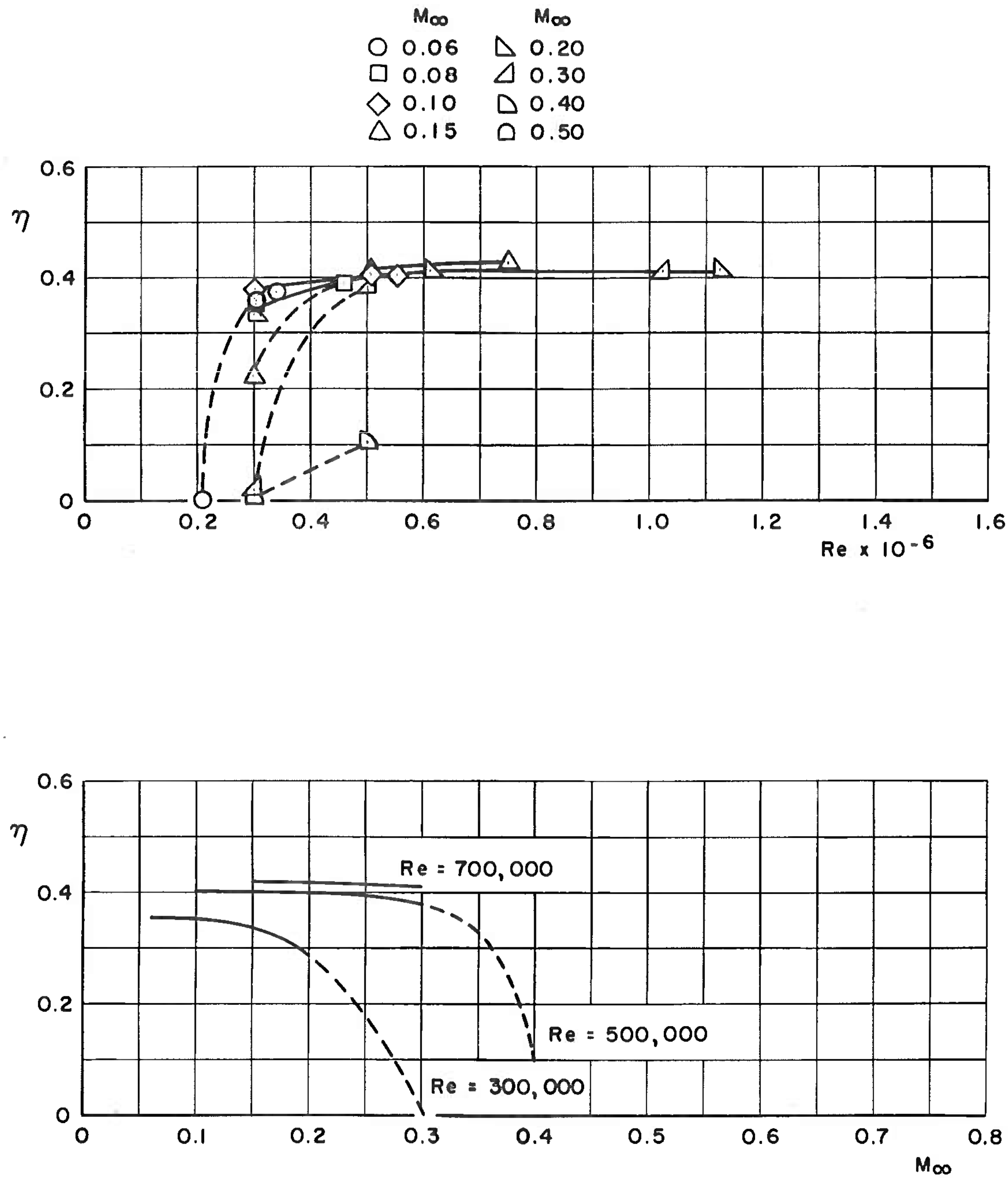
Fig. 8 Variation of Pressure Efficiency with Reynolds Number and Mach Number for the 22-deg Diffuser with and without Ribs





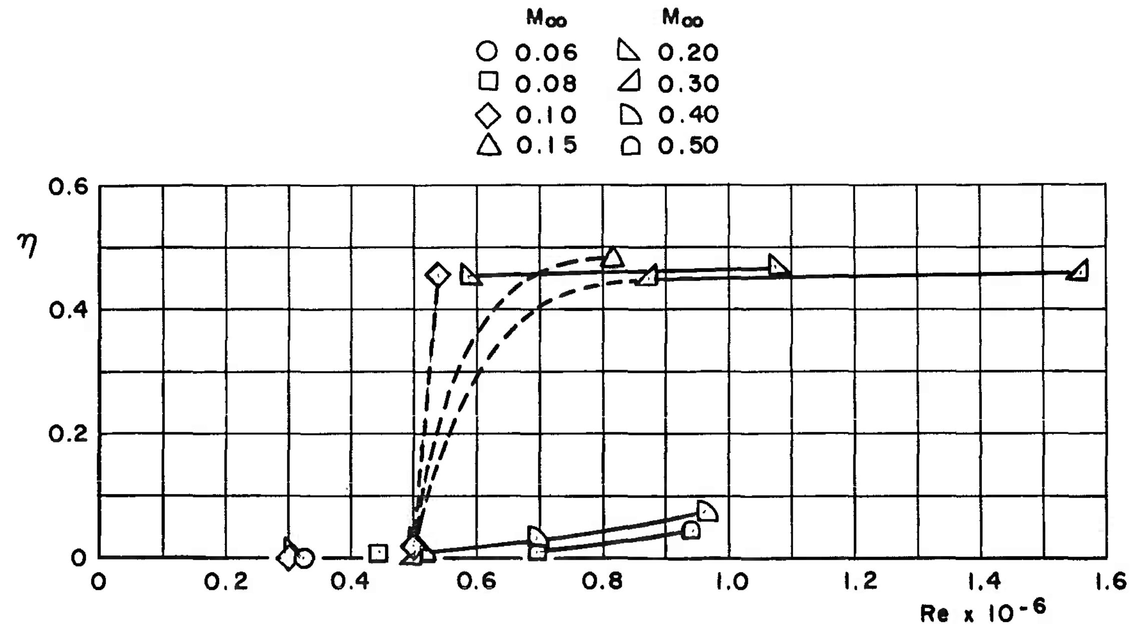
b. Configuration 1

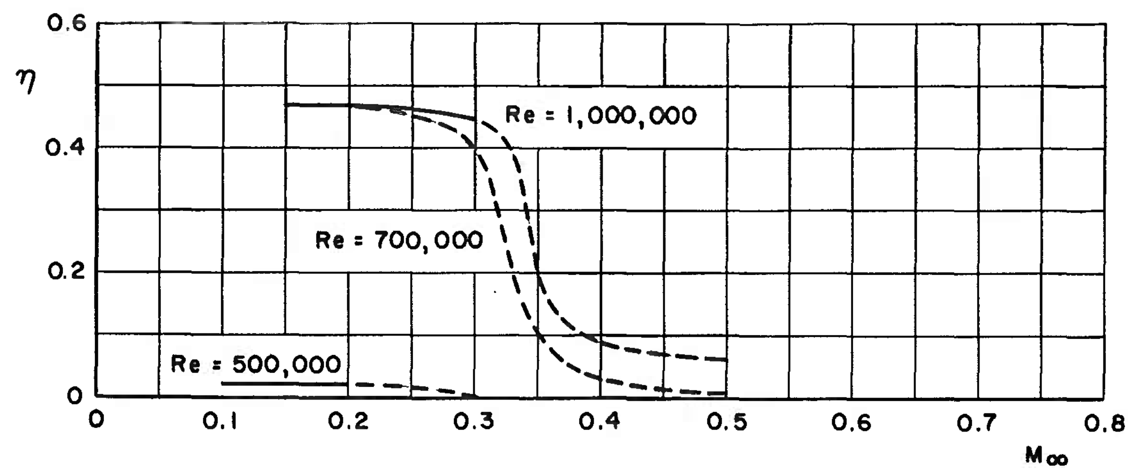
Fig. 8 Continued



c. Configuration 3

Fig. 8 Continued





d. Configuration 8

Fig. 8 Concluded

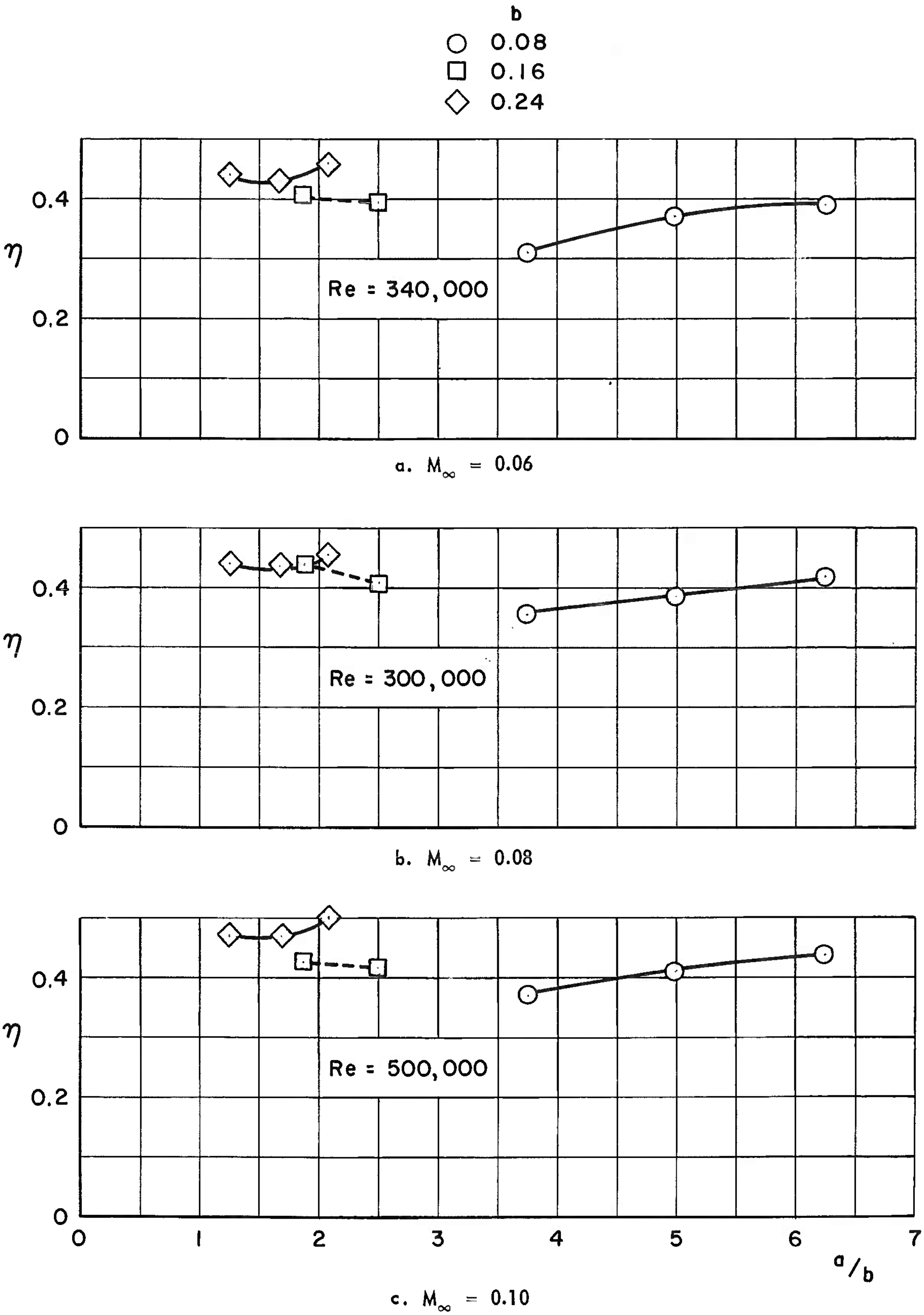
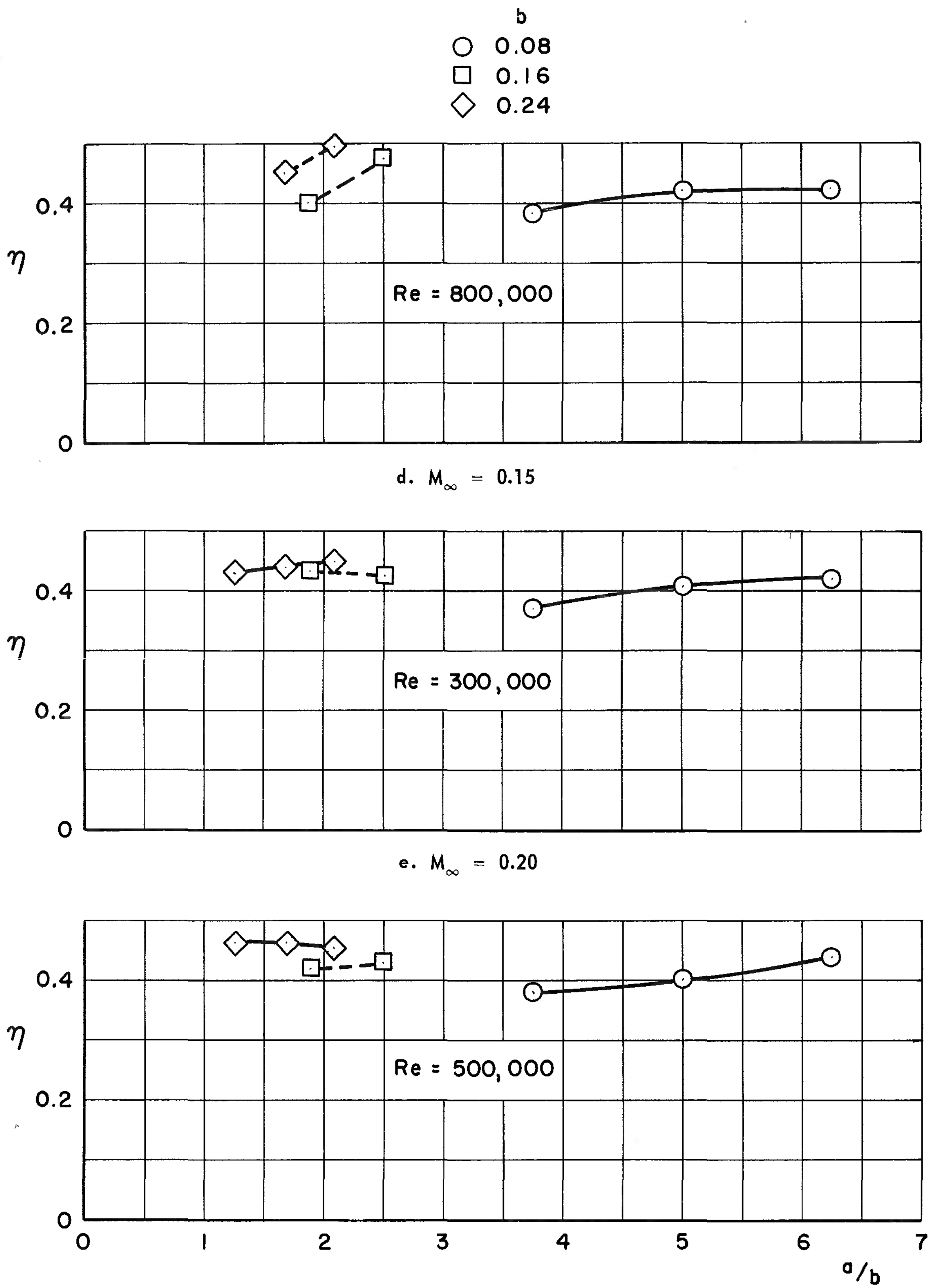


Fig. 9 Variation of Pressure Efficiency with Groove Depth-to-Width Ratio for the 20-deg Diffuser

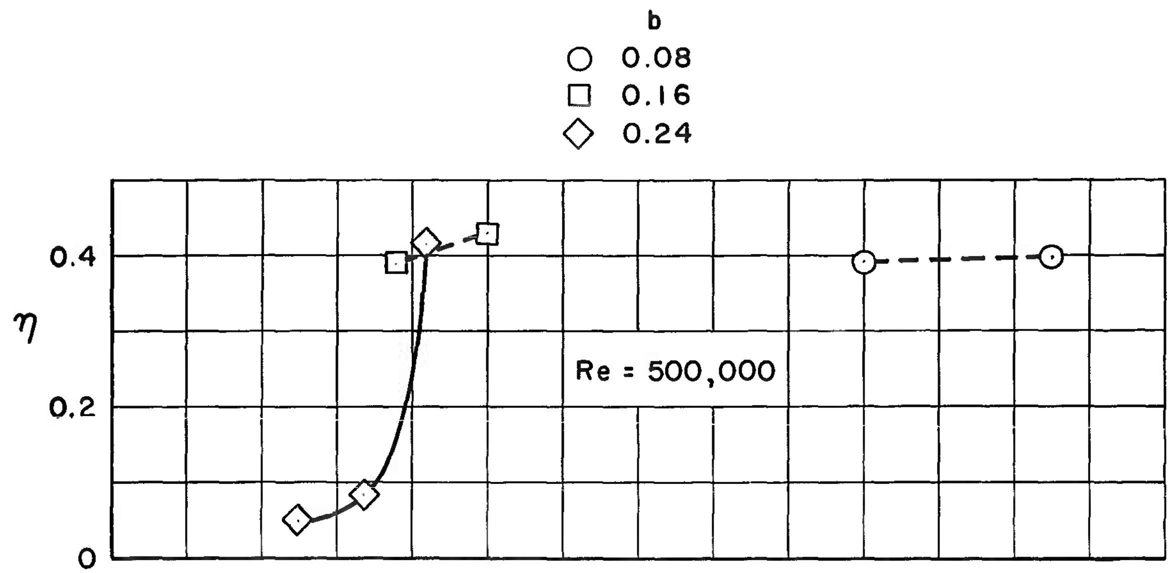


d. M_∞ = 0.15

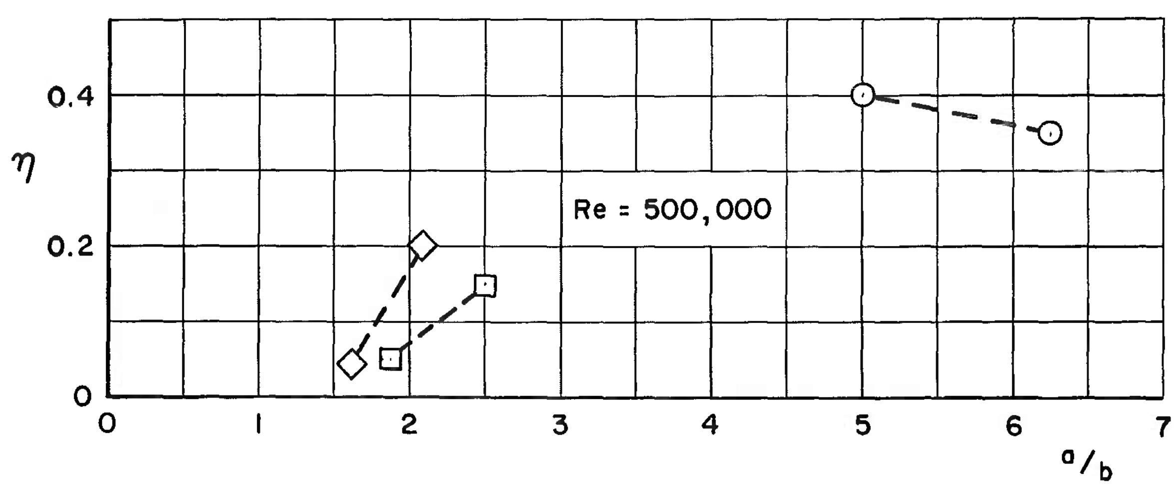
e. M_∞ = 0.20

f. M_∞ = 0.30

Fig. 9 Continued

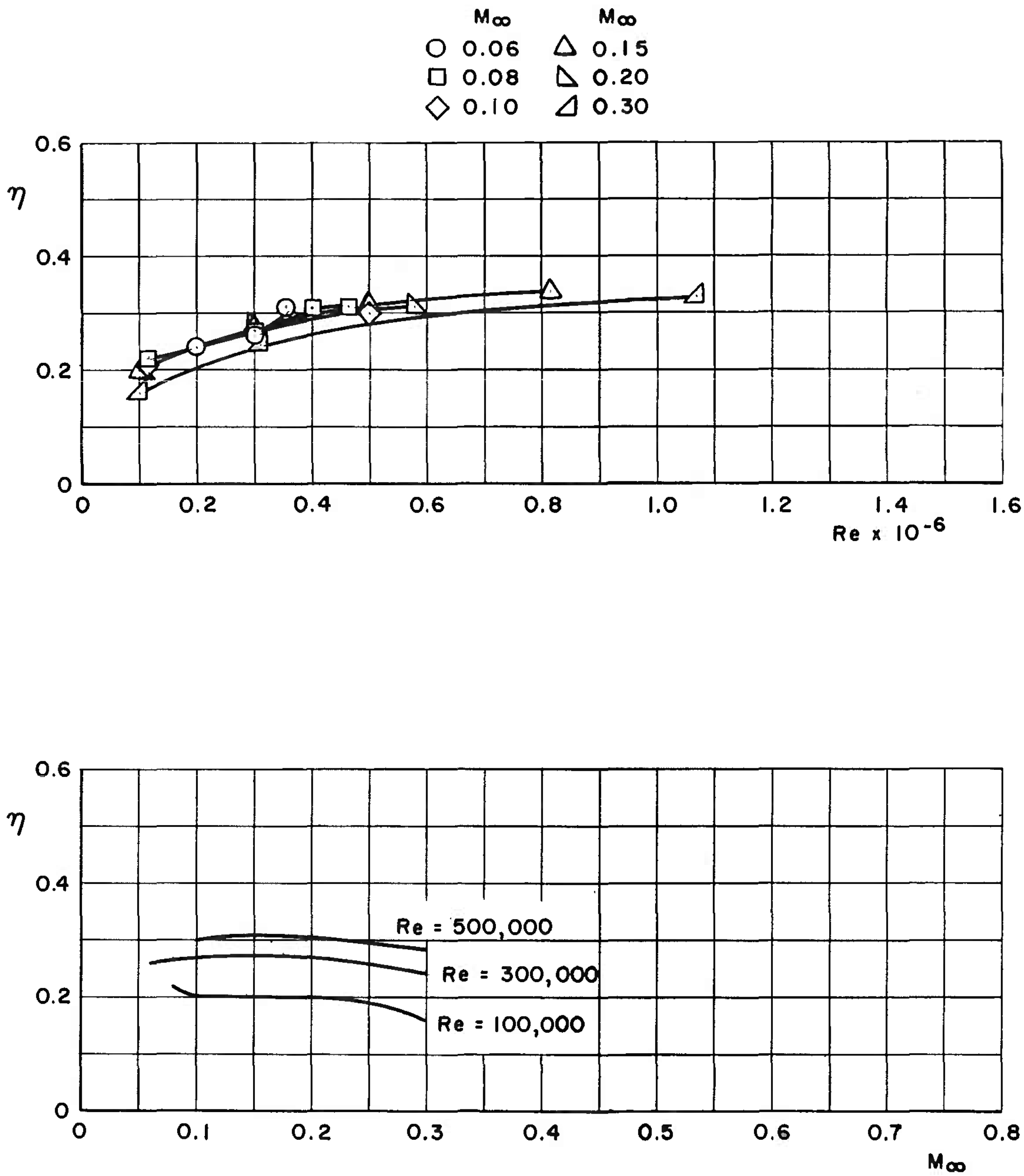


g. M_∞ = 0.40



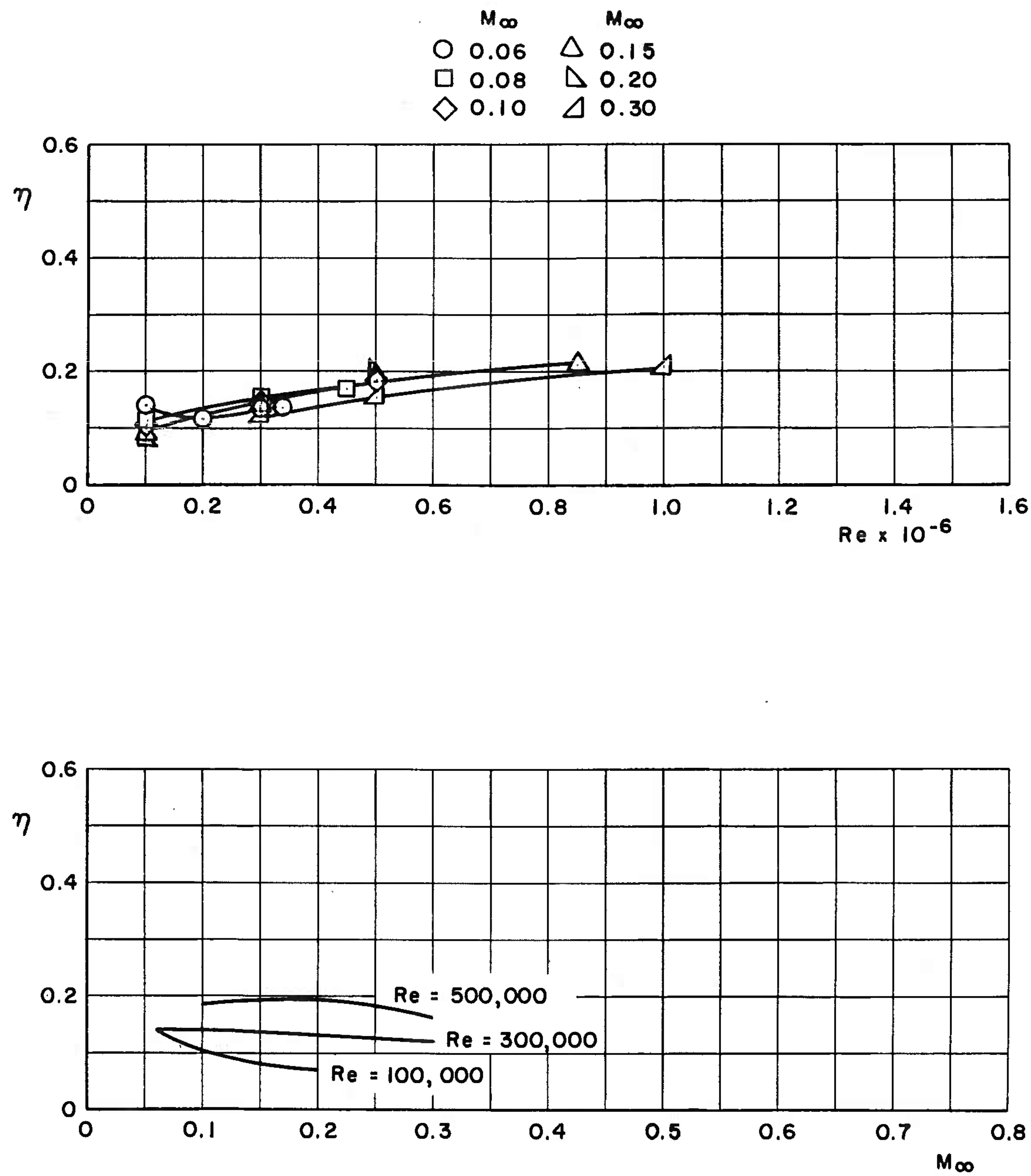
h. M_∞ = 0.50

Fig. 9 Concluded



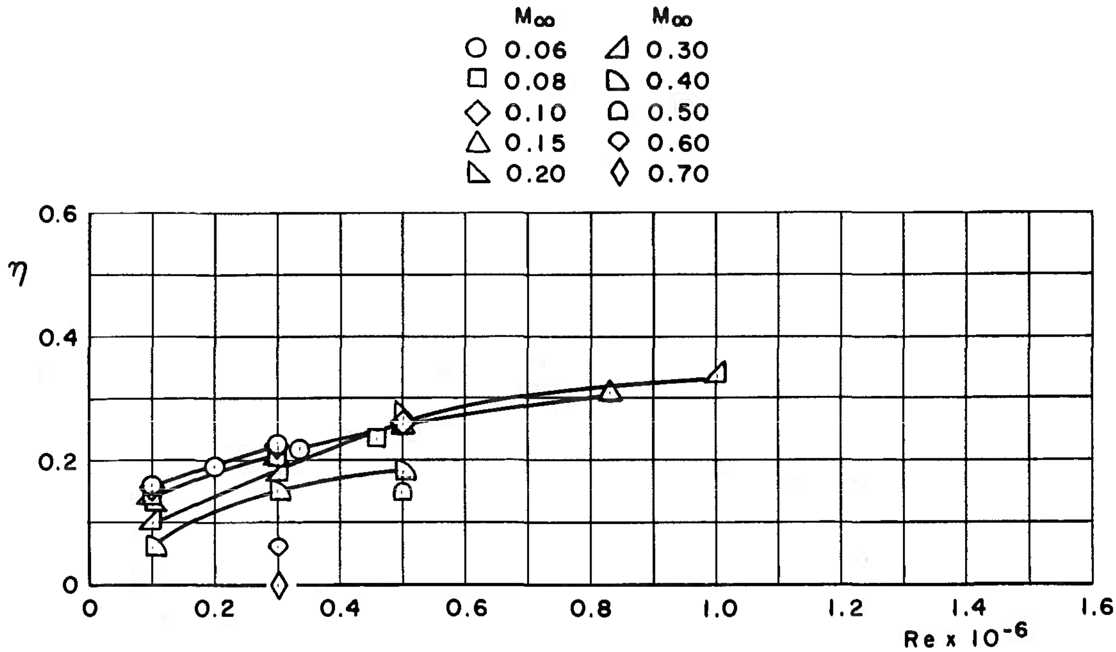
a. Vortex Generotor Configurotion 2, θ = 20 deg

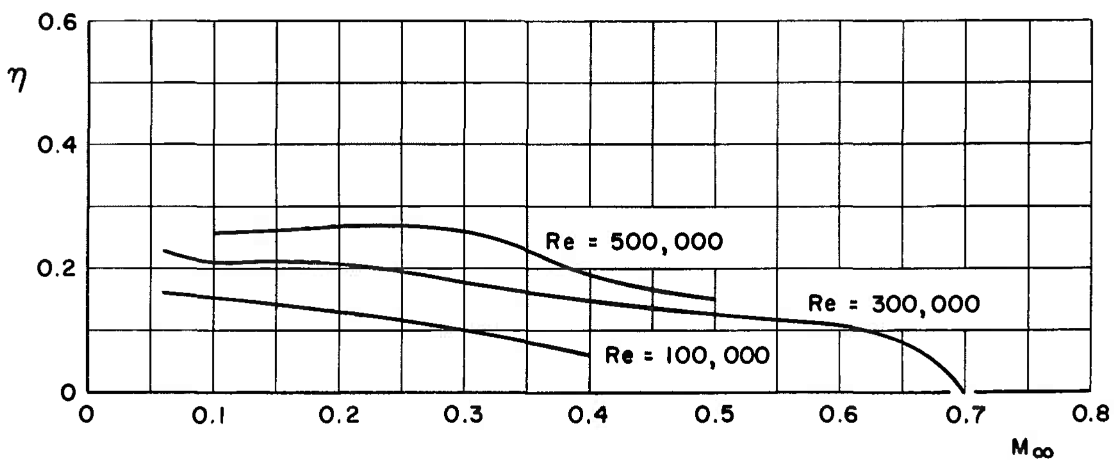
Fig. 10 Voriation of Pressure Efficiency with Reynolds Number ond Mach Number for the 20- and 22-deg Diffuser with Vortex Generators



b. Vortex Generator Configuration 1, θ = 22 deg

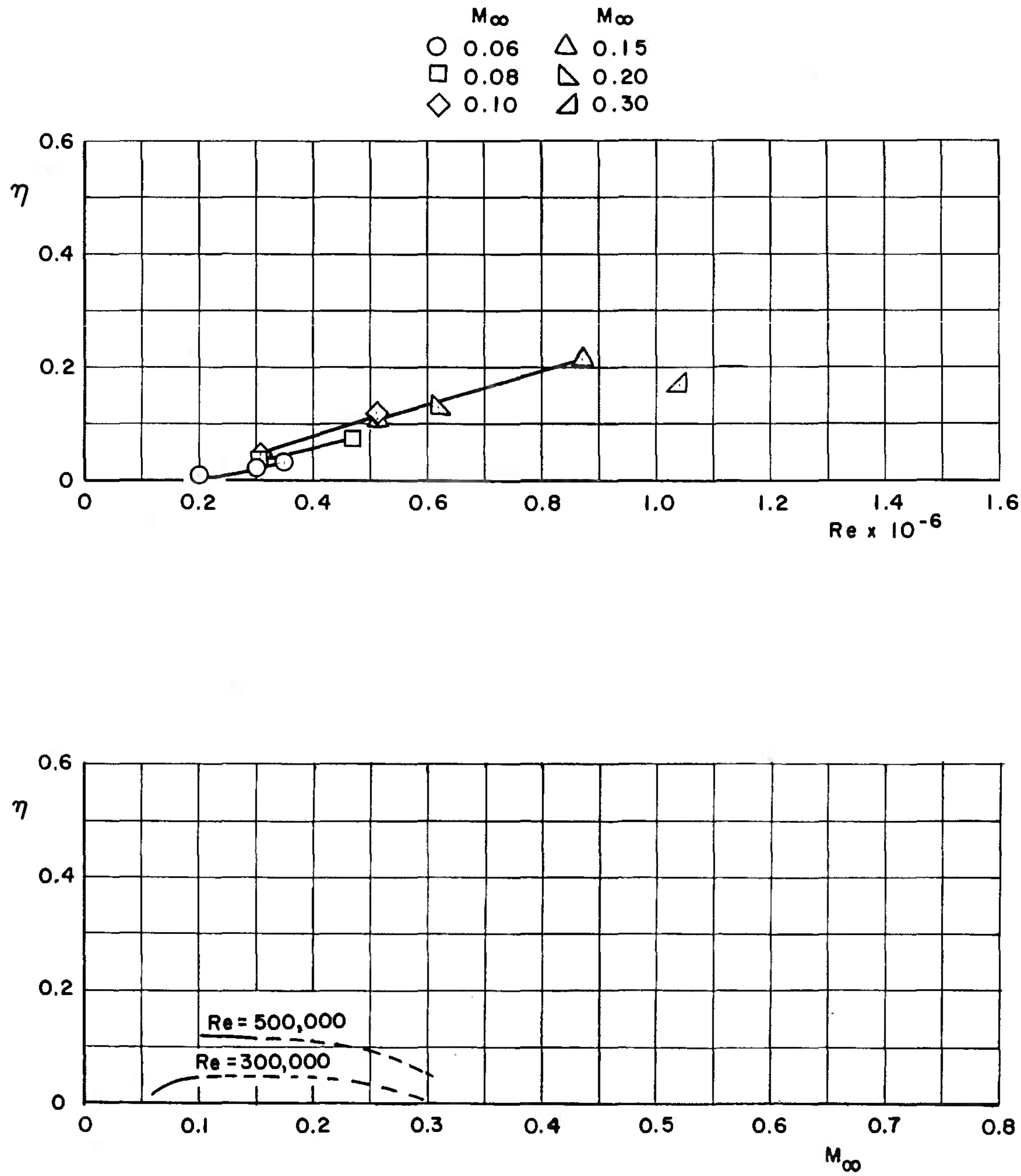
Fig. 10 Continued





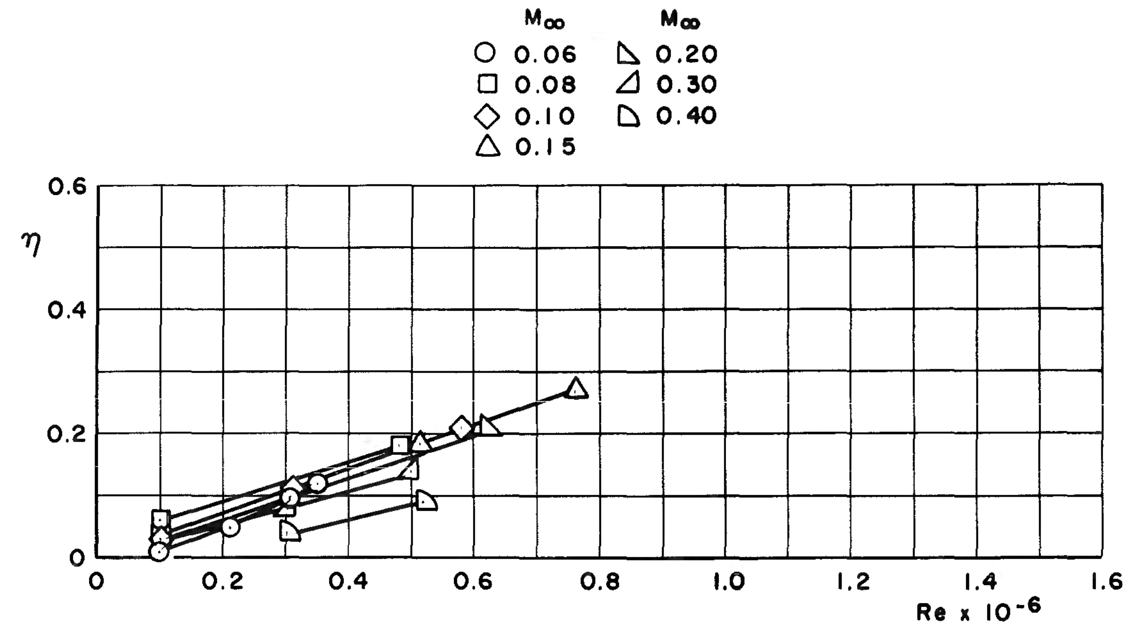
c. Vortex Generator Configuration 2, θ = 22 deg

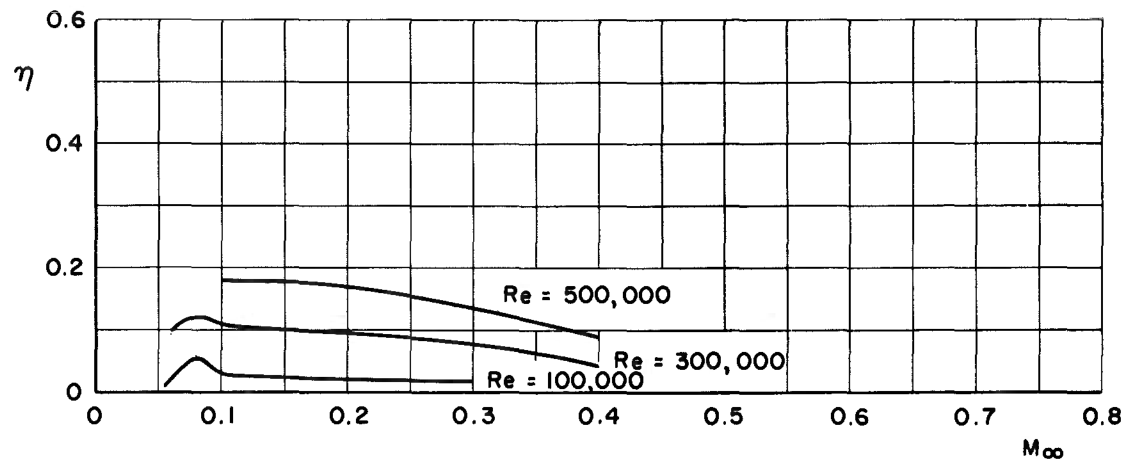
Fig. 10 Continued



d. Vortex Generator Configuration 3, θ = 22 deg

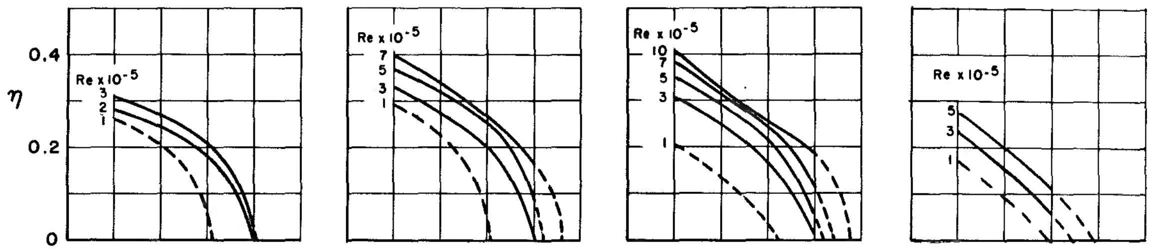
Fig. 10 Continued



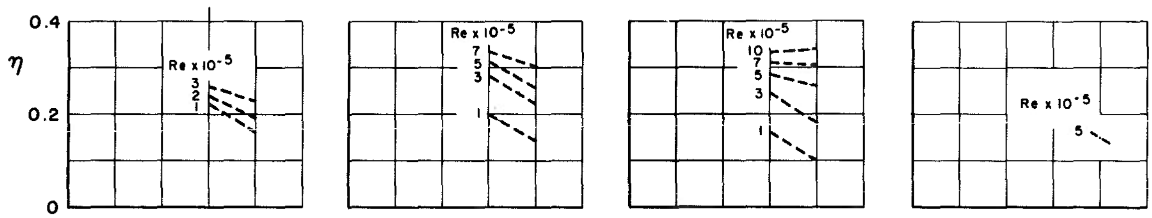


e. Vortex Generator Configuration 4, θ = 22 deg

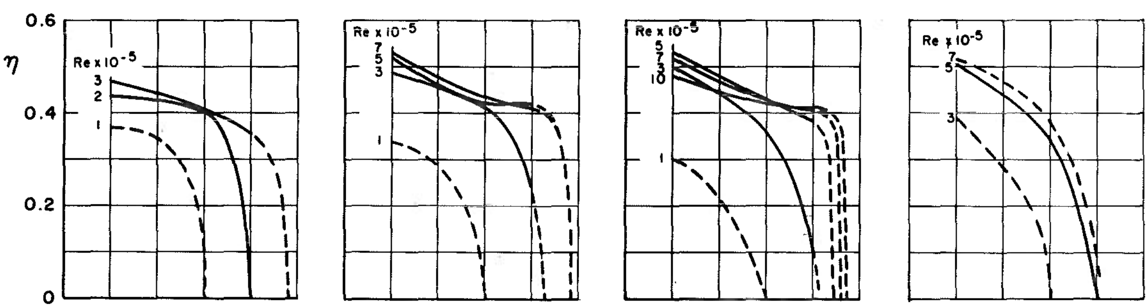
Fig. 10 Concluded



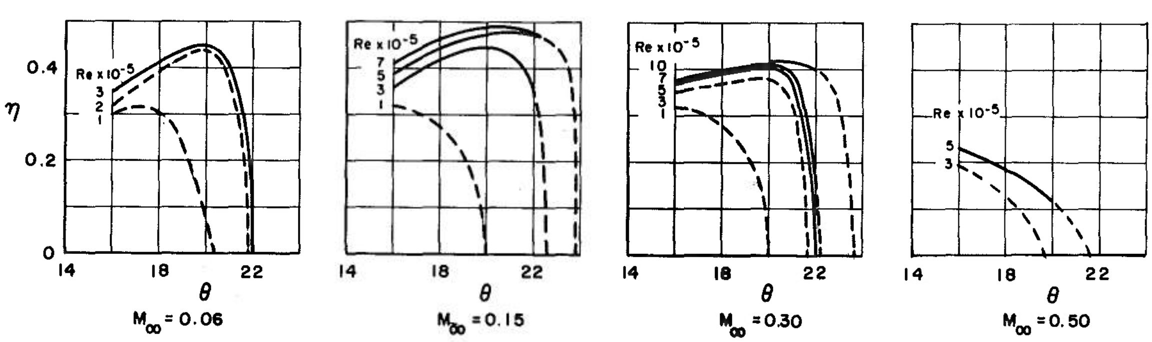
a. Smooth Diffuser



b. Vortex Generator Configuration 2

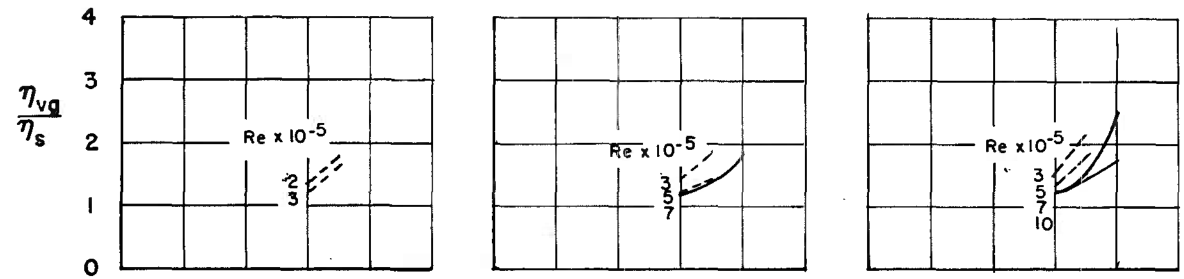


c. Rib Configuration 3

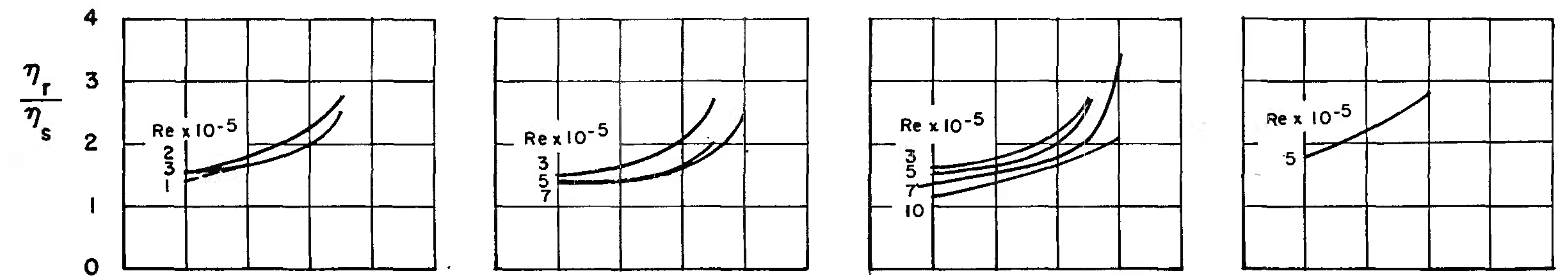


d. Rib Configuration 8

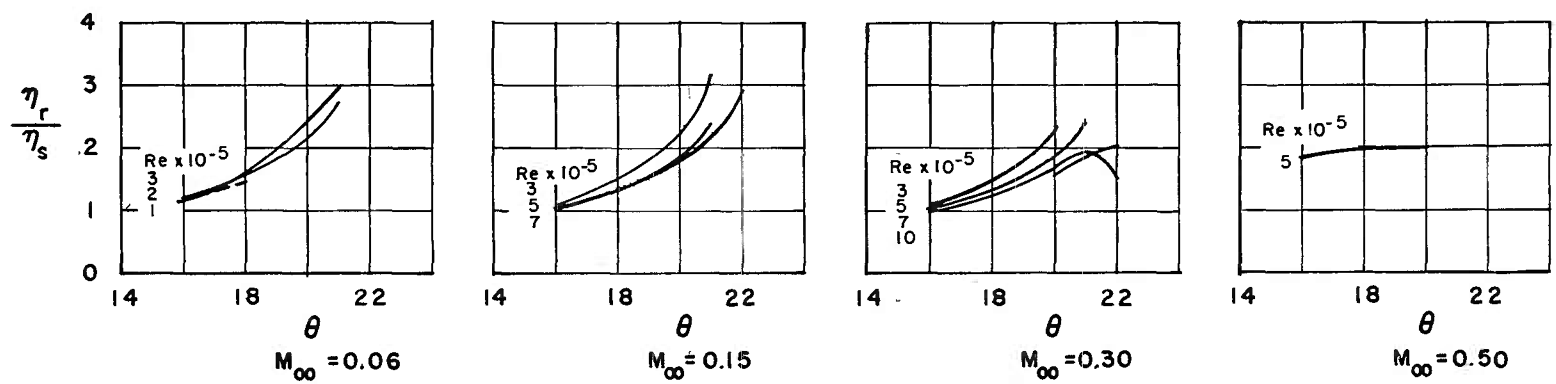
Fig. 11 Variation of Pressure Efficiency with Diffuser Angle



a. Vortex Generator Configuration 2



b. Rib Configuration 3



c. Rib Configuration 8

Fig. 12 Variation of η_r/η_s and η_{vg}/η_s with Diffuser Angle

TABLE I
SUMMARY OF U.S.S.R. TESTS

Test	Diffuser Type		D_1, mm	D_2, mm	L, mm	β	a, mm	b, mm	t, mm	d, mm	n	V_α, m/sec	Re x 10^{-5}	η_r / η_s
1	Conical	Rib	30	96	100	34	4	2	1	unk	32	unk	0.5 to 1.0	0.7 to 2.0
1	Conical	Smooth	30	96	100	34	–	–	–	–	–	unk	0.5 to 1.0	0.7 to 2.0
2	Conical	Rib	30	96	100	34	6	2	1	unk	1 to 30	unk	0.9 *	1 Rib: 1.49; 5 Ribs: 1.80; 30 Ribs: 1.84
2	Conical	Smooth	30	96	100	34	–	–	–	–	–	unk	0.9 *	
3	Conical	Rib	unk	unk	unk	40	unk	unk	unk	4	unk	unk	0.5 to 6.0*	unk
3	Conical	Smooth	unk	unk	unk	40	–	–	–	–	–	unk	0.5 to 6.0*	unk
3	Multistage		unk	unk	unk	11	–	–	–	–	–	unk	0.5 to 6.0*	unk
3	Separating Walls		unk	unk	unk	unk	–	–	–	–	–	unk	0.5 to 6.0*	unk
4	Conical	Rib	100	Varied by β	195	22,31,40,60	7	3	1.5	3	11	10 to 110 for β = 31	unk	31 deg: 1.42
4	Conical	Smooth	100	Varied by β	195	22,31,40,60	–	–	–	–	–	10 to 110 for β = 31	unk	40 deg: 2.45
4	Annular	Rib	100	Varied by β	195	22,31,40,60	7	3	1.5	3	11	10 to 57 for β = 40	unk	31 deg: 1.37
4	Annular	Smooth	100	Varied by β	195	22,31,40,60	–	–	–	–	–	10 to 57 for β = 40	unk	40 deg: 2.37
5	Flat One Side Expanded	Rib	90 by 70	180 by 70	235	θ = 22 deg	See Fig. 1	See Fig. 1	1.5	3	See Fig. 1	unk	unk	See Fig. 1
5	Flat One Side Expanded	Smooth	90 by 70	180 by 70	235	θ = 22 deg	–	–	–	–	–	unk	unk	See Fig. 1

* Reference length for Reynolds number unknown.

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

N/A

5. AUTHOR(S) *(Last name, first name, initial)*

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13. ABSTRACT

Tests were conducted to determine the effects of a ribbed wall on the efficiency of a single side expanded, wide angle, subsonic diffuser. Rib geometry, diffuser angle, Reynolds number, and Mach number were varied. Except at low Reynolds numbers, ribs were found to improve the efficiency of the diffuser. They were also more effective than vortex generators except at low Reynolds numbers for all Mach numbers and at high Mach numbers for all Reynolds numbers. The ribs produced maximum improvement at diffuser angles of 20 to 22 deg. The data indicated that the depth-to-width ratio of the grooves between the ribs should be in the range of 2 to 6. The range of Reynolds numbers and Mach numbers over which the ribs were effective appeared to be primarily a function of the groove width.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
diffusers - subsonic						
ribbed wall						
vortex generators						

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